HURRICANE WEATHER RECONNAISSANCE

HEARINGS

BEFORE THE

SUBCOMMITTEE ON NATURAL RESOURCES,
AGRICULTURE RESEARCH AND ENVIRONMENT

OF THE

COMMITTEE ON
SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED FIRST CONGRESS

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HURRICANE WEATHER RECONNAISSANCE

FRIDAY, APRIL 7, 1989

House of Representatives, Committee on Science,
Space, and Technology, Subcommittee on Natural
Resources, Agriculture Research and Environment,

Washington, DC.

The subcommittee met, pursuant to call, at 1:47 p.m., in the Commission Chambers Room, Port of Palm Beach, No. 4 East Port Road, Riviera Beach, Florida, Hon. Tom Lewis presiding.

Mr. Scheuer. Good afternoon. I am Congressman Jim Scheuer from New York and I am Chairman of the Subcommittee on Agriculture—on Natural Resources, Agriculture Research and Environment of the Congressional Science, Space, and Technology Committee on which your Congressman Tom Lewis serves with such great distinction.

The Subcommittee will come to order and we will now consider the issues of hurricane forecasting and surveillance.

As many of you know, the United States suffers more extreme weather incidents, weather happenings than any other country in the world by far. We have a thousand tornadoes a year, we have ten severe storms, we have another ten hurricanes or comparable storms capable of causing severe damage. So this means that in many parts of the United States we are threatened with serious weather incidents that destroy property in the hundreds of millions of dollars a year and reap a terrible toll in terms of accidents and lives that are lost. And lives are lost because of the inadequacy of the Weather Service and the fact that it is operating with 1950s technology.

We had a hearing a couple of months ago in North Carolina where I enjoyed the assistance of Congressman David Price and Congressman Tim Valentine. We had testimony from the National Weather Service people there, and the regional National Weather Service people there, who indicated that the National Weather Service was in desperate need—they used the words "desperate need"—of upgrading.

Now here we have, even as we speak, the reports in today's issue of the Palm Beach Post, a very thoughtful well-written article on hearings that were held yesterday on the occasion of the three-day National Hurricane Conference. Fortunately one of the most thoughtful witnesses, William Gray, is with us here today. He was quoted in the lead story in the Palm Beach Post as having said some very interesting and significant things as to why our country is at risk and why Palm Beach and similarly situated coastal areas are even more at risk.

He gave us a little comforting news that the probability of having hurricanes as intense as Hurricane Gilbert, you know that ravaged Jamaica, and Hurricane Joan which ravaged Guatemala, are not as serious this year as they were in 1988 or 1985. But then he told us in effect to fasten your seatbelts for the era of the 1990s, and he said his outlook was not as favorable in the next years. To quote, "The next decade may see continuously busier hurricane seasons with more powerful storms like those of the 1950s and the 1960s."

He sits there in his area in Colorado watching his computers and so forth—he will tell us later on—but he sits there in his area looking at the continuous reports that flow across his desk and he is concerned that extremely dry conditions off western Africa, which have persisted since 1970, these dry conditions which ameliorate the effect of hurricanes. These conditions will diminish over the next few years and south Florida should be prepared for such a possibility.

It would appear that major increases in hurricane-spawned coastal destruction is inevitable, and this year drought conditions will prevail probably in west Africa, indicating a mild hurricane season, but that this cannot be expected to continue as an ameliorating factor. And therefore the continuation of unsatisfactory or threatening weather conditions in west Africa are going to continue to have a clearly predictable effect on weather in the United States and in particular weather in the coastal regions of Florida.

Now I am going to ask—make a suggestion as a layman—and I hope Mr. Gray will correct me if I am wrong—that the continuing process of global warming means that as the sea level rises as a result of global warming, as a result of the melting of the arctic ice floes, that there will be more vulnerability as a result of hurricane action that stimulates real problems emanating from the ocean. As the oceans rise we are going to—our coastal areas are going to be more and more vulnerable. And that makes it extraordinarily important that we have the time, the safety margin of adequate time to predict these hurricane occurrences, which in turn makes it terribly important that we constantly monitor weather conditions off the coast of west Africa.

Now we had two satellites up there until January of this year, until roughly a month or six weeks ago. And with those satellites—one covered the entire Pacific area and one covered the entire Atlantic area over to and including west Africa. But when one of those satellites conked out about six weeks ago, we had to refocus the remaining satellite. We had these two satellites focused, one on the east coast and one on the west coast to include the far reaches of the Pacific Ocean and the far reaches of the Atlantic Ocean. Now we have the remaining satellite focused over the middle of the United States so we can cover all of the continental United States—that is obviously a desirable and necessary thing, but what it means is that it does not stretch beyond Hawaii going east and it does not stretch anywhere near the coast of Africa going west. So we do not get up to date kind of information on weather conditions in west Africa, off the coast of west Africa. We have to wait a day or more before we know that, and before that kind of essential information can be cranked into the computer and factored into our early warning hurricane alerts.

So here you have a direct connection between our ability as a nation to detect and analyze, evaluate and disseminate information about weather conditions off the coast of west Africa—a direct connection between that and our ability to warn the farmers in Florida, consumers in Florida, radio and television stations, newspapers so that they can disseminate early warning signals about weather. What could be a more extraordinarily interesting example of the ability of high technology to serve human needs, and what could be a more grave warning of the results of our country's inability to stay current at the state of the art, the computer sciences, satellite sciences, the fact that we are largely functioning with 1950s in the beginning of the 1980s, and the damage in terms of human health, human life, not to say property, that occurs because of our negligence and our lack of foresight in funneling top technology to these extraordinarily important problems.

Now we have with us Congressman Jim Sensenbrenner of Wisconsin and I would like to yield to him for his comment.

Mr. SENSENBRENNER. Thank you very much, Mr. Chairman. The House Committee on Science, Space, and Technology plays a key role in authorizing funds for all civilian scientific research throughout the Federal Government. And a key component of our authorization role is doing the research authorization for NOAA, the National Oceanic and Atmospheric Administration, of which the Weather Service and the Hurricane Center are parts.

Accurate weather forecasting is not only vital from a public safety standpoint, but also very useful for both agricultural and commercial decisionmaking. And that is why it is important that we keep our technology at the state-of-the-art because what we do can prevent lives from being lost and property from being damaged, as well as allow our farmers and our commercial enterprises to make as big a profit as they possibly can.

Congressman Lewis has been a leader in this area during the now eight years that I have been privileged to serve with him on the House Committee on Science, Space, and Technology. I certainly would like to salute him for bringing this hearing to Florida to point out what needs to be done in terms of more accurate hurricane predicting, particularly in light of the predictions that the decade of the 1990s is going to be far worse from a hurricane standpoint than the last decade has been.

Thank you.

Mr. SCHEUER. Thank you, Congressman.

I too want to express my appreciation to Congressman Tom Lewis for inviting the Subcommittee down here, especially on such a beautiful day. I might say we are expecting snow in Washington this evening, so it is a special pleasure for me to be here.

Congressman Lewis has established himself as an unusually capable and thoughtful member of Congress. He has made pioneering efforts in the field of aviation safety and the field of high speed rail transportation and every aspect of the environment from acid rain to clean water that is a serious problem down here. He has really won the respect and the admiration of Members of Congress from across the entire spectrum of issues and I might say across party lines. Our Committee has never operated in a partisan fashion and all of us on both sides of the aisle have enormous admiration for your Congressman for his high intelligence, his deep dedication, his ability to work hard and master the issues and know what he is talking about at all times. We really admire him and respect him and value him.

Therefore, since he has made a specialty of hurricane warning, an issue that is so important and significant, not only to the life and the economy of this area of the Nation, but to the life of its people, I would like to ask Congressman Lewis to accept the gavel and take charge of this hearing. Congressman.

Mr. **Lewis**. Thank you very much, Chairman, and thank you very much for those kind words.

I want to welcome you and other members of the Natural Resources, Agriculture Research and Environment Subcommittee to Florida. Hurricane forecasting and reconnaissance is an important issue and Mr. Chairman, your leadership in this area has been an important factor in making sure that the Federal Government adequately supports the program. The citizens of Florida join with me in thanking you for your continued support.

You and the Subcommittee have provided leadership in numerous other Florida related issues. For example, in March, 1983, you brought the Subcommittee to West Palm Beach to convene a hearing on the Federal agriculture weather program. The program continues today as a result of that hearing.

I want to thank you, Jim, for taking the time. You are a long way from Wisconsin and a long way from Washington. To come down here for the hearing is certainly appreciated and I am sure that everyone here in Florida as a result of this hearing will certainly value your input. I also thank you for your kind words.

This morning I spoke at the National Hurricane Conference in Miami and several of those participants will be witnesses here today. I can report that the interest in maintaining a strong program in hurricane forecasting and reconnaissance is greater today than ever before.

I recently visited the Severe Storms——

Mr. **Scheuer**. Congressman, would you yield for just a moment?

Mr. **Lewis**. I certainly will.

Mr. **Scheuer**. I omitted to say in my opening remarks something that I heard about this morning with the greatest of pride and pleasure. Namely, I was just informed an hour ago that your Congressman Tom Lewis received an award this morning at the National Hurricane Conference in Miami for his successful efforts in preventing the Federal Government from discontinuing the hurricane surveillance aircraft program. And this is only one tiny example of the high diligence and continuing dedication with which Tom Lewis carries on his constant surveillance over the effectiveness of government, not only in serving the nation but certainly perhaps even more important from your point of view, serving the interests of this community and the State of Florida. Tom, I congratulate you for that remarkable recognition, we are all proud of you.

Mr. **Lewis**. Thank you, Mr. Chairman. You know, I will save a lot of those warm fuzzies——

[Laughter.]

Mr. LEWIS. Thank you.

I recently visited the Severe Storms Lab in Oklahoma and the National Hurricane Center in Miami and from my observations and talks with scientists, good progress is being made in understanding hurricane formation and behavior. But the progress has not come easily.

For a time, the long-term future of the Air Force WC-130 hurricane reconnaissance program was uncertain. Last Congress, I introduce House Concurrent Resolution 366 which called for the continuation of this program.

The Hurricane Conference passed a resolution this morning endorsing the continuation of aircraft reconnaissance. In the interim, the Air Force has agreed to continue that program and we feel it will now be a matter of policy well into the late 1990s. Today, they will give the Subcommittee an overview of their plans.

But this is not the end of the story. What happens after the WC-130 program? How can we improve the accuracy of prediction on forecasting the path of hurricanes? What is the long-term future of hurricane surveillance?

As many of you know, and the Chairman mentioned it, there is only one GOES satellite in orbit now. The geostationary operational environmental satellite gathers data on hurricanes. The next generation of satellites is not expected to be launched before mid-1990. What will be the impact if the existing satellite fails before a replacement is in orbit?

Of even more concern to me is the focus and direction of the research program in hurricane surveillance. Recently I came across a startling fact that the accuracy of hurricane forecasting has not improved significantly since the early 1960s. My question is what are we doing with the millions of dollars that have been spent in the last 25 years? Do we have a research program directed toward eliminating errors in forecasting?

This hearing will try to address some of those issues and I hope work toward developing a coherent long-term hurricane surveillance research program.

Again Mr. Chairman, I want to thank you. I would also like to comment your staff, the Subcommittee staff, and especially Curt Stanford, Dr. Jim Greene of my Washington staff, and my Florida staff for their excellent work in preparation for this hearing.

And now I would like to ask Dr. Sheets if he would come forward as our first witness. We are very pleased to have Dr. Sheets with us today. Dr. Sheets—certainly I took a lot of bows for the continuation of the hurricane reconnaissance but certainly not without his help and his motivation and encouragement, as well as the work that he did in continuing the reconnaissance.

Dr. Sheets is probably the most well-known individual in hurricane forecasting not only in the United States but in the world, he is one of the foremost experts. It is a great privilege, Dr. Sheets, to work with you and Neal Frank in this area and we are certainly pleased to have you with us here today.

Dr. SHEETS. It is my pleasure, sir.

Mr. **Lewis**. The statement of Dr. Sheets will be made a matter of the Committee record and you are free to give your testimony at this time.

STATEMENT OF DR. ROBERT C. SHEETS, DIRECTOR, NATIONAL HURRICANE CENTER, NATIONAL WEATHER SERVICE

Dr. **Sheets**. Again it is a real pleasure to be here and I thank you for coming and certainly the delegates, and particularly Congressman Lewis, in recognizing the problems that we have relative to hurricanes. Those who may have attended our National Hurricane Conference over the past three days down there in Miami, and I know several of the news media did that, they learned a lot.

This morning there were some big issues about conflicting information, uncertainties in forecasts and how those are being used. What I would like to do—I have a little booklet that I passed out and if you will flip over there to the first set of pictures, what I want to do is to not really read the statement that is there because that is there and that is lengthy, but I want to just point out—

Mr. **Scheuer**. A picture is worth a thousand words.

Dr. **Sheets**. Exactly right.

Mr. **Scheuer**. I think your pictures are worth a million words.

Dr. **Sheets**. Thank you, sir.

What I am trying to do is just to lay a quick background as to what the hurricane problem is and later on in that, I tried to do some things to bring home to everybody on the Committee—unfortunately I do not have anything for Wisconsin here. I just did not bring anything for Wisconsin.

Mr. **Scheuer**. What do you have for the Bronx?

Dr. **Sheets**. For the Bronx, well essentially that, we have Atlantic City, that is close. Right?

Mr. **Scheuer**. Right.

Dr. **Sheets**. So I am going to try to lay out the hurricane problem here. The first set of pictures, basically what you see there is the Richelieu apartment complex. Everybody that has been involved in hurricanes since 1969 has seen these sets of pictures. The one reason for showing them is the before and after pictures of the Richelieu apartment complex which sits down on the ocean, basically the Gulf of Mexico there, and you see it before and after. Once before with 25 people in it and once afterwards with 23 of them dead. It is totally destroyed. The point being why we have to evacuate areas that are on the immediate coast. That means the barrier island areas or right on the immediate coast in some way. So that is the main point that I want to make. That very graphically illustrates why we must evacuate those people in those vulnerable areas.

Now flipping to the next page tells us the kinds of problems that we have. There are a couple of graphs there, and as I said, I tried to illustrate this, that it is not just a Florida problem. For instance on the left, the diagram there is the Texas coastal county population growth from 1900 to 1985. If you look at that curve you see that it is growing rapidly and in fact, the population there has nearly doubled in the last two decades in the coastal counties.

These are the people who live in the areas that must be evacuated, the large populations are there.

And then you look over there to Florida coastal county population, we have now around nine million people in our coastal counties. And right here in Palm Beach of course, people recognize the fact that we are growing very rapidly in the Palm Beach area, southwest Florida area. So we have got Texas, we have got Florida.

The next diagram is that of the east coast, and what I did there was combine Virginia, Maryland, Delaware and New Jersey. It is not just a problem in Florida, it is a problem along the Gulf coast, it is a problem along the east coast and again this is only the coastal county populations.

Now let us try to put in perspective what this means in terms of people and people that have to be moved in the particular case of a hurricane coming along, and the uncertainties in forecasts and the uncertainties in the measurements of intensity. The next set of pictures you have there, at the top of the picture—and we have got about three of those—you will see the green areas that are on those maps. The top of that is the Galveston-Houston area and there is a little black line that goes through there and it shows the track of a category two hurricane on the Saffir/Simpson scale. I want to point out that we use a scale of 1 to 5. So one is the weakest, 5 is the strongest. Twos and threes are all I am going to show you. I am not going to show you the extreme here in these cases, these are just the average hurricanes, in the middle, twos and threes. Category two hurricane on that track going into Galveston. The area that is indicated in green would be inundated by the storm surge and therefore must be evacuated.

Now let us assume that that hurricane is 20 miles per hour stronger, only 20 miles per hour stronger. Instead of 90 miles per hour or 95 miles per hour, it is 115. The difference between the two is what is shown in the bottom map there. Now all you have to do is go back—take that same hurricane, this last model indicates what areas would be covered by the storm surge, and you go back and look at that map and look at the areas covered by green as compared to the areas covered by green in the top map, the difference is 200,000 people. Not knowing the strength of that hurricane, the wind field distribution, within 20 miles per hour means 200,000 people on one case there in Galveston, Texas.

So let us take that one step farther. If we do not know the strength of the hurricane within 20 miles per hour, we have got two choices; one is to warn for the next category. If we think it is a category two, then we warn for a three. That is one compensating way that we can do that. If we do that, that means that we move 200,000 people unnecessarily. Or vice versa, if we think it is a two and it turns out to be a three and we warn for a two, we have got 200,000 people at risk. So those are the numbers that we deal with with a 20 mile per hour uncertainty. That is Galveston-Houston.

The next map, next page, is New Orleans. For those not familiar with New Orleans, New Orleans of course is below sea level, it is surrounded by a levy system and again, the green area on the top there, that is a category two. The green area in the bottom is a category three hurricane. Hurricane Betsy reclaimed a lot of that land around Lake Pontchatrain. Again, several hundred thousand people are affected with the difference only being 20 miles per hour assuming a perfect track forecast. We have not even talked about the accuracy of the forecast in terms of its track, just the wind field.

Then the next page is called Figure Number 10 I guess. That is the Gilbert type hurricane coming in from the east/southeast into New Orleans. That means 18 to 20 feet of water in downtown New Orleans. We know there is no way we are going to get all those people out of those particular areas. So that is an issue we have in terms of people, in terms of vertical refuge.

It is not just Texas, it is not just Louisiana. The next set covers part of your area of responsibility, Congressman Lewis, I believe and that is the Port Charlotte/Fort Myers area, coming right into those areas, and certainly impacting these areas. The same kind of thing, I will not go into the details of that, but all you have to do is look at the area in green, the top picture, versus the area covered by green in the lower picture, and again realize that many, many thousand people difference between those two categories.

Then as I say, we wanted to do something for the east coast, that is Charleston in the next series. I will not dwell on that, the same story there.

And then we go to our favorite area called Atlantic City. Atlantic City, New Jersey, a lot of money up there, a lot of money being expended in the casinos up there, and there is a great reluctance to close those casinos. If we have a hurricane moving up the coast and put out a hurricane warning, I understood at one stage there was several hundred or even a few thousand dollars per second that are cut off if we put a warning up there. How important is it to get that warning as accurate as we can possibly make it to the people in Atlantic City.

If you are not familiar with that area, again, they have several hundred buses that arrive from Philadelphia, Washington, New York, taking people to Atlantic City every day. There is not even room enough to park those buses on the island, so they drop the people off in the morning, take the buses inland, park them and at night they go back and get them. There is not room enough on that island to park the vehicles of the people who work on the island, so they park on the causeways that go into Atlantic City. As a result of that, you can imagine the evacuation problem that we have in that community. Again, the difference between a category two and three hurricane is shown there.

Then finally, what we have been highlighting at the National Hurricane Conference that has just been going on in Miami, and that is what-if Gilbert. Now Gilbert is an extreme event, no question about it. And all the ones I have just presented to you are not extreme events, the average kind of events, the category twos and threes.

In the picture on the left, that is hurricane Gilbert, a satellite picture of hurricane Gilbert superimposed to scale over south Florida. I asked the Conference when I presented this, how many people are being affected by that hurricane simultaneously. Well certainly you are in Palm Beach, as well as Dade, as well as Broward, as well as Monroe County, but also over on the west coast, right on up the west coast. So roughly five million people are probably experiencing hurricane force winds within a few hours of that system moving across there.

We went a scenario there showing what that meant in terms of the storm surge, and that is the picture over on the right side and the fact that Key Biscayne, Miami Beach, downtown Miami area right at the Hyatt Regency where we were at today, would be somewhere around 10 to 12 feet of water, all underwater, all would have to be evacuated under those conditions.

Now what about the chances of these happening. Building codes, all kinds of problems that we encounter there. The next set of pictures are major hurricanes, that means category threes, fours, and fives, and I will reiterate that the ones I have showed you are twos and threes. So these are threes, fours, and fives.

For the decade of the 1940s you will notice that here in south Florida, here in the Florida peninsula, we had a major hurricane in 1944, 1945, 1947, 1948, 1949, and two in 1950. There were also some minor hurricanes in there. There were two on the Gulf coast, one up the east coast, the 1944 hurricane that gave a lot of problems to New York as a matter of fact.

Then we go to the decade of the 1950s and we have most of the hurricanes up the east coast. Only Donna comes across the Florida peninsula and Audrey in the Gulf coast, Audrey killed around 500 and some people over in the Louisiana area.

Now in the decade of the 1940s, those hurricanes that struck south Florida, that is when Palm Beach, Dade County, Monroe County, Broward County got their good building codes. And we wish those good building codes were around the country, not just here in south Florida, but were also around the other sections of coastline. And indeed, if they were, we would suffer a lot less damage and a lot less potential loss of life.

The next set shows what happens in the 1960s, so we had the 1940s over Florida, 1950s up the east coast, the 1960s it is almost all in the Gulf coast, only Betsy in 1965 that brushed this area, to the south of here through the Florida Keys and Dade County and then went up into the New Orleans area. Then we look at—that is the 1960s and 1970s. We had a reduction in the number of hurricanes that occurred during that period.

And then the decade of the 1980s, you will see a considerable reduction in the numbers of storms that occurred there. Only three hurricanes so far, major hurricanes, so far in the decade of the 1980s, and I sure hope we do not catch up this year. This is the last of—hopefully that will not take place.

So what we have had, at the same time that we have doubled our population in Florida, we have had less than half the number of hurricanes that we had in the previous two decades. So the problem is actually being compounded.

The next figure there shows the dollar loss. Up until we had this big reduction in the numbers of hurricanes in the decade of the 1980s, we were growing at a rate of about quarter to half a billion dollars per year increase in the losses due to hurricanes. If we average loss today, considering just normal kind of statistics, somewhere around $1.5 billion every year as a result of hurricanes.

The figure on the right is the loss of life. And the loss of life has gone down markedly as you can see there. The largest natural disaster in the history of the United States was the great Galveston hurricane in 1900. And it is over 6000 people. The person from Galveston today said they just stopped counting after they got to 6000, so it was well over 6000 people. And as I go along the coastline today, I find only about 10 percent of the people who live in the hurricane prone areas ever heard of the great Galveston hurricane. Then I will say how many people heard of the great San Francisco earthquake and everybody has heard of that. We lost a little over 600 people in the earthquake, but we lost over 6000 here, and again it can happen in the future.

We have been very fortunate that we have been able to reduce that loss of life. How have we reduced that? Gotten people away from the funnel. We have moved them inland in these hurricane evacuation areas and been able to get them away from that problem and we have not had a drowning until Gilbert I understand. We did have one in the Caribbean from Gilbert, but we have not had a drowning in the last decade from people being in those hurricane prone areas.

I do not think I will go into the next diagram or two, but basically this is some of the information that is fed back to us from the reconnaissance aircraft, research aircraft, the new aircraft that are coming on board from the Air Force airplanes, and indeed the detailed information we get from those aircraft allow us to resolve is it a category two or is it a category three, how large is the wind field, what areas will be impacted by the storm surge. Without the reconnaissance aircraft, our studies indicate that our forecast error would increase by roughly 20 percent, so that means we would have to warn over a fairly large area, a little bit larger area.

It costs today over $50 million to prepare a coastline for a hurricane making land fall, the average warning area is roughly 300 miles, it costs over $50 million to do that today. Increase that by 20 percent, you have just expended another $10 million every time you raise a warning, and it has nothing to do with whether or not the hurricane ever strikes. That is just warning or no warning. It has nothing to do with loss of business, that is just the preparation costs that were involved. So there is a big expense that we have to go to, to prepare for hurricanes, and a lot of lives at risk. We are very thankful again that Congressman Lewis and others have seen fit to provide us the kind of systems that we need to go along with our forecast capabilities.

Thank you.

[The prepared statement of Dr. Sheets follows:]

STATEMENT OF
DR. ROBERT C. SHEETS, DIRECTOR
NATIONAL HURRICANE CENTER
NATIONAL WEATHER SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U. S. DEPARTMENT OF COMMERCE

BEFORE THE

SUBCOMMITTEE ON NATURAL RESOURCES, AGRICULTURE
RESEARCH AND ENVIRONMENT OF THE
COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
U.S. HOUSE OR REPRESENTATIVES

April 7, 1989

Mr. Chairman and Members of the Subcommittee:

My name is Dr. Robert C. Sheets. I am Director of the National Hurricane Center for the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce.

Tropical cyclones are recognized as nature's most destructive phenomena due to their frequency of occurrence and size. In the Atlantic, and Eastern and Central Pacific, they are called hurricanes. In the Western Pacific, they are called typhoons and elsewhere they are called tropical cyclones. In 1970, the loss of life resulting from a single tropical cyclone striking Bangladesh has been estimated to exceed 500,000 people with some estimates of 1 million dead. In 1900, a hurricane struck Galveston, Texas resulting in more than 6,000 deaths. This is the largest natural disaster in the history of the United States. By comparison, the great San Francisco earthquake resulted in a little over 600 deaths. Nearly 2,000 deaths were experienced in the offshore islands near Charleston, South Carolina from a hurricane in 1893. Nearly the same number of deaths resulted from the 1928 hurricane that emptied Lake Okeechobee onto the surrounding communities of Florida. In 1926, a hurricane caused major damage in southeast Florida with estimates of loss of life ranging from near 250 to 500. In 1935, a hurricane striking the Florida Keys killed more than 400 people. A hurricane in 1947 produced wind gusts to 155 mph just south of Palm Beach County at Hillsboro Light and in 1969, Camille struck the Mississippi coast with winds estimated to be near 175 mph and gusts near 200 mph. This hurricane produced a storm surge (dome of water accompanying the storm as it moved ashore) of 25 feet above normal with waves on top of that.

Over the past few years, we have been able to get the great majority of the people away from the immediate coastal areas where the potential for large loss of life exists when a hurricane strikes. However, it is becoming more difficult each year to evacuate people from these areas due to rapidly increasing populations and roadway systems that have not kept pace with the population growth.

Given that we have a lot of people in these exposed areas, let us examine the probable risk they face. The National Weather Service (NWS) has developed a model that is used to predict what coastal area will be covered by the rising water when the hurricane approaches. The maps produced are used by State and local officials to determine evacuation zones for various strengths of hurricanes. Traffic studies are then done to determine required evacuation times. These studies to date have been quite revealing, but also frightening.

One scenario is that you think it is a category 2 hurricane and it turns out to be a category 3. The result could be thousands of people trapped on barrier islands or other high risk areas. The second scenario is that you think the hurricane is a category 3 and it turns out to be a 2. Now you have caused as many as 200,000 people to take actions that were not necessary if accurate intensity forecasts were available.

The combination of the risk factor and the uncertainties in the forecasts present major dilemmas for forecasters and local and state emergency management officials. Preparations for hurricanes are expensive. The average warned area when a hurricane is forecast to move inland on a path nearly perpendicular to the coast is about 300 miles wide. The average cost of preparing that size of area for the hurricane, whether it actually strikes or not, is more than $50 million.

Of even greater concern than the economic factor is the protection of life. For safety reasons, a degree of overwarning is necessary because of the uncertainties involved in hurricane forecasting but if we consistently overwarn by wide margins, people will not respond and such actions could result in large loss of life. To get a proper response from the general population, we and local and State officials must maintain credibility. To do so, we cannot treat all hurricanes as if they were Camilles or Gilberts! This admonition also applies to the media. This exaggerated approach may indeed provide maximum protection of life this time, but endanger many more lives the next time when people refuse to respond when, in fact, the danger may even be greater than the previous time.

Now, I would like to focus on specifics of the observing and forecast problems for the tropics and associated technology.

Hurricane forecasts have improved slowly over the past few decades and I fully expect the rate of improvement to increase over the next 5 to 10 years. Meteorological satellites played a significant role in this improvement, partially replacing weather ships, several down-range upper air stations from the early space program, the routine synoptic pattern aircraft reconnaissance data and other key observations. The satellites, specially-placed buoys and improved numerical models have partially offset these deficiences. However, future improvements will depend upon the quality and quantity of data available to us over the tropical and subtropical regions of this hemisphere and in the hurricane and its near environment.

Today, the geosynchronous satellite is our first line of defense against the hurricane threat! It is the single most important observing tool available to the tropical meteorologist and hurricane forecaster. This is the means by which we continuously monitor the vast tropical and subtropical regions of our hemisphere. Without this capability, we would need a huge fleet of aircraft to monitor the oceanic areas of interest and would still likely miss significant storm developments. Indeed, prior to the days of satellite, the U.S. Air Force and U.S. Navy flew standard reconnaissance flights almost every day over portions of the Gulf of Mexico, Caribbean Sea, and North Atlantic Ocean. When some potential area of development was noted, additional flights were concentrated on those areas. With the satellite, we are able to be much more selective in the utilization of the very limited reconnaissance aircraft resources. We can pinpoint where and when we need to send aircraft to obtain more quantitative data in the core of hurricanes or their precursors.

Although satellite technology has improved markedly over the years, it is still not sufficient in-and-of-itself to provide the quantitative information needed for computer models for global and hemispheric prediction nor for severe weather forecasts and warnings in the tropics or at mid-latitudes. That is, although the satellite data are vital to the forecast and warning process, present remote sensing capabilities are not sufficient to replace upper air "soundings" or standard surface observations. Even with the dense network of hourly surface observations and upper air "soundings" available over the continental United States, mid-latitude forecasters expect to supplement those data with doppler radar (NEXRAD) in order to reduce false alarms and improve warnings.

Over the tropics and subtropics, data problems are much more severe than over the mid-latitudes. The geosynchronous satellite provides considerable information on flow patterns at upper and lower levels in the troposphere, but little detail in the mid-troposphere (10,000 to 20,000 feet). Our studies to date tell us that this is the most critical region for obtaining improvements in hurricane track forecasts for time periods greater than 24 to 36 hours. Over the continental United States there are upper air "soundings" available for about every 40 thousand square miles. By comparison, over a major portion of the tropical and sub-tropical Atlantic, there is only one such station (Bermuda) for about 4 million square miles.

Sounding data are being obtained from polar orbiting satellites as well as from the VISSIR Atmospheric Sounders (VAS) onboard the GOES satellites for oceanic regions as well as over land. These data are extremely valuable over oceanic regions as they are essentially all that are available. However, the quantitative estimates of the thermal and moisture distributions using these remote sensing capabilities are marginal at best for depicting the subtle changes in the moisture laden tropical atmosphere that can result in major weather changes. At the same time, the only realistic hope of obtaining these needed data over the oceanic areas would seem to be from remote sensing from satellites. GOES NEXT is expected to provide significant improvements in sounding capabilities. In addition to improved sounding capabilities, advancements in numerical modeling and analysis techniques must be made to make optimum use of these forms of data.

The second line of defense against the hurricane threat is reconnaissance aircraft. The aircraft are the only means of making direct measurements of location, strength and windfield distributions critical to the hurricane forecast and warning process. For the hurricane forecaster, this measurement system is equivalent to doppler radars and dense hourly surface observations for the mid-latitude severe weather forecaster. The Improved Weather Reconnaissance System (IWRS) presently being installed on U.S. Air Force aircraft has taken advantage of developments from NOAA's research aircraft. These systems provide detailed information on the wind fields and strength of the hurricane via a satellite data link to the National Hurricane Center for use in the critical warning periods.

In your folders are some examples of the types of information provided by these aircraft during hurricane Gilbert of 1988. The little flags indicate the wind speeds in knots. These observations are transmitted from the computers onboard the aircraft through the satellite to computers at the National Hurricane Center where they are plotted out only seconds after the last value of each 30-minute sample is recorded onboard the aircraft. These figures are overlayed on radar observations from NOAA's research aircraft. The first figure shows a horizontal depiction of the radar return while the second figure shows the "eyewall" to the left and right of the aircraft while it was in the "eye" of Gilbert.

These highly accurate measurements of wind fields are used to estimate damage potential and to determine the extent of the areas of warnings as well as the time when strong winds will arrive on the coasts. In addition, these wind fields are critical for making realistic estimates of the expected storm surge, that dome of water that accompanies a storm as it moves onto the coast. As I stated earlier, and showed with the prints of the potential storm surge for some selected coastal regions, relatively small changes in the wind field can result in major changes in areas of inundation.

Aircraft do an excellent job in providing the detailed information in the core of the hurricane. It is this region in which remote sensing technology from satellites is most limited. There is presently no means of estimating detailed wind distributions from satellites in this core region and even determining center positions is a problem unless there is an "eye" present. A new Air Force satellite uses a microwave sensor to try to depict structure similar to that shown by conventional radar. The resolution, of course, is much poorer, but indeed such depictions can greatly help in center determinations. Sensors on this same polar orbiting satellite attempt to estimate surface winds. However, present capabilities do not permit reasonable estimates in the core of the storm. Also, the frequency of observations is highly limited by the polar orbit constraint.

Although aircraft do an excellent job in obtaining information over the limited area near the core of the hurricane, they are too slow to obtain comprehensive data over the large areas surrounding the storm. By contrast, satellites provide nearly instantaneous views over large areas. In addition, geosynchronous satellites provide routine coverage over these large areas at 30-minute intervals and through animation, general flow patterns can be depicted. It is impossible to obtain this type of information from aircraft. The result is that these two types of data sources are quite complementary. The aircraft resource is then used quite selectively with limited use over the open waters and increased coverage during critical warning periods.

Finally, when a hurricane approaches the coast of the continental U.S. the coastal NWS radar network comes into play. These systems as well as coastal surface and buoy observations are used to "fine tune" the warnings in terms of timing and last minute deviations along the coast. All of these observations are supplementary and complementary to the satellite and reconnaissance aircraft observations mentioned earlier. The limited effective range of these radar systems (less than 200 miles) usually means that warnings will already be in place prior to the center of the hurricane being observed on the radar. However, for systems developing near, or moving nearly parallel to, or stalling near the coast (such as hurricane Elena off the Florida west coast) this radar network can become primary in the warning process.

The addition of the doppler capabilities of NEXRAD will be of special importance in these situations or other rapidly developing situations such as a storm that suprised us along the Florida west coast in 1982. Coastal residents in that case were shocked to awaken to early morning warnings and winds of 60 mph and water rises of five feet. In addition, reconnaissance aircraft do not fly in hurricanes over land. The doppler capabilities will provide much needed information on changes of wind fields over land with height which hopefully will permit us to make more refined warnings in the future. In addition to the wind and storm surge problems associated with hurricanes is inland flooding due to heavy rainfall. The NEXRAD system should aid in improving rainfall forecasts and permit better warnings for inland river flooding such as that of hurricane Agnes in 1972. The remnants of Agnes caused major flooding from North Carolina through Pennsylvania and New York with the loss of 122 lives and $2 billion in damage.

At the same time we are improving observations, through NEXRAD and GOES-NEXT, we must become more efficient in accessing, processing and analyzing the large quantities of data from numerous sources and utilize that

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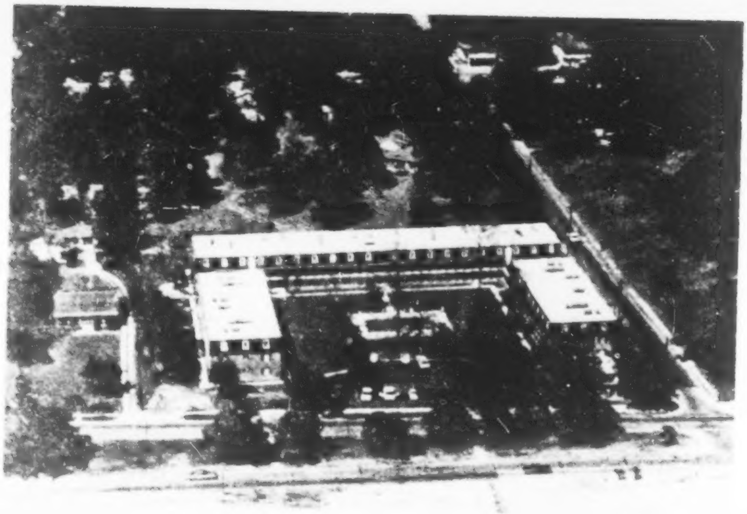
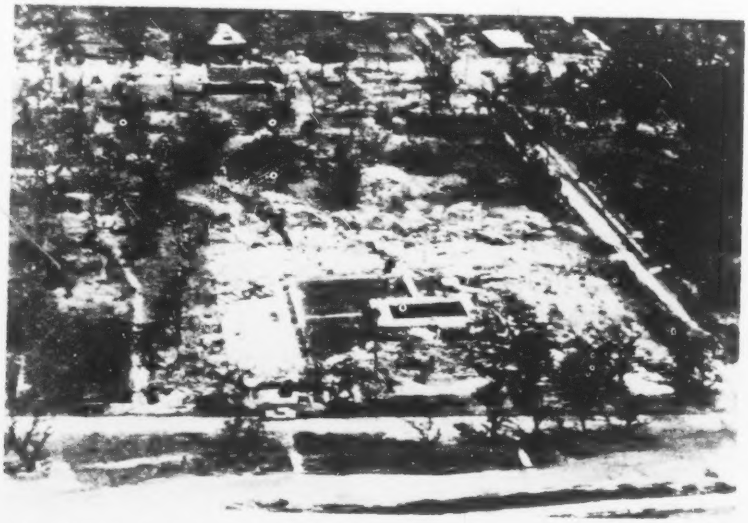
information in improved computer models run on fast computers. It is envisioned that the class VII computer scheduled for the National Meteorological Center at Suitland, Maryland, will permit operational implementation of next generation hurricane prediction models. Finally, we need to provide products to users which optimize desired responses. The planned AWIPS system is envisioned as the primary tool for accomplishing this task. Critical meteorological information required by local, State and Federal officials and perhaps private industry, can be displayed graphically and either accessed or transmitted to users. For example, warning areas, predictions of coastal flooding, expected rainfall, maps of probabilities, etc., would be generated and made accessible to users. Providing a uniform product for these users should then minimize chances of confusion and result in a more effective warning and evacuation process.

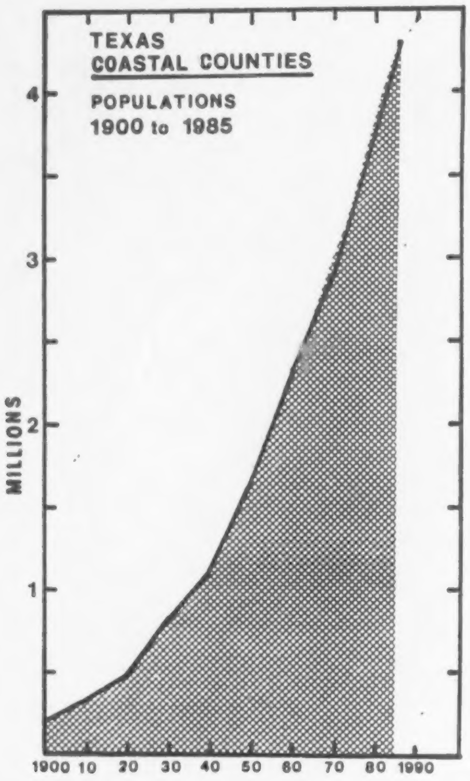
In summary, I believe advancing technology is providing us the opportunity to greatly improve our forecast and warning programs. However, the spiraling upward trend of economic losses due to hurricanes will continue as a result of increasing coastal populations and insufficient building codes. In addition, if we do not provide for adequate means of evacuation and/or places of refuge for residents in existing and planned communities, we will almost assuredly see a significant increase in loss of life due to hurricanes.



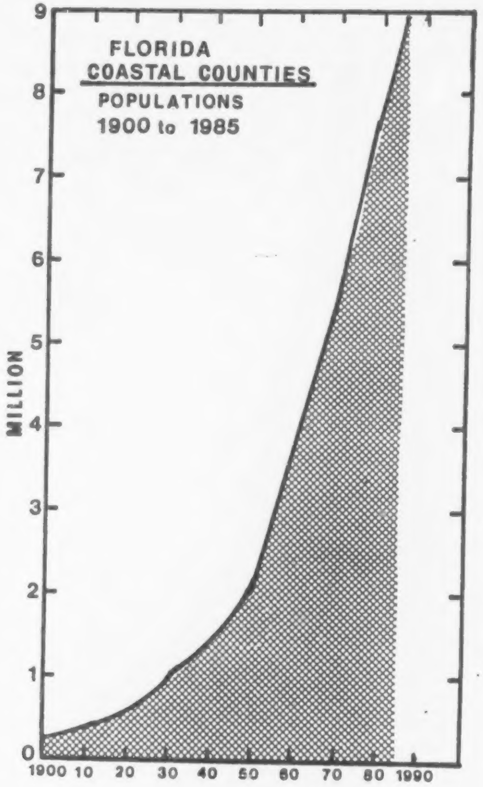
1. Richelieu apartment complex in Pass Christian, Mississippi before hurricane Camille of 1969.



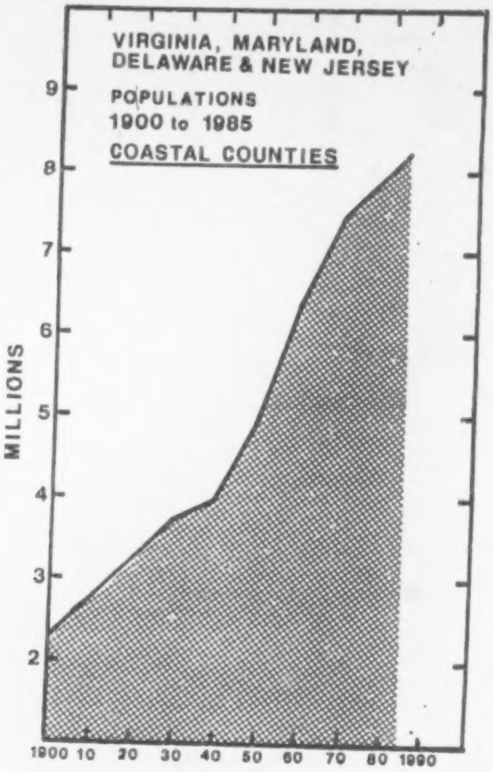
2. Richelieu apartment complex after hurricane Camille demonstrating the power of the rising waters (storm surge) and waves associated with hurricanes. Twenty three people died in this building. Residents in such areas must be evacuated before the hurricane strikes.



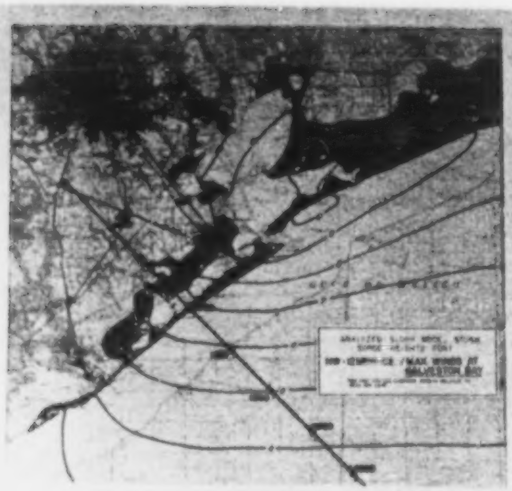
3. Coastal county populations for the state of Texas from 1900 to 1985.



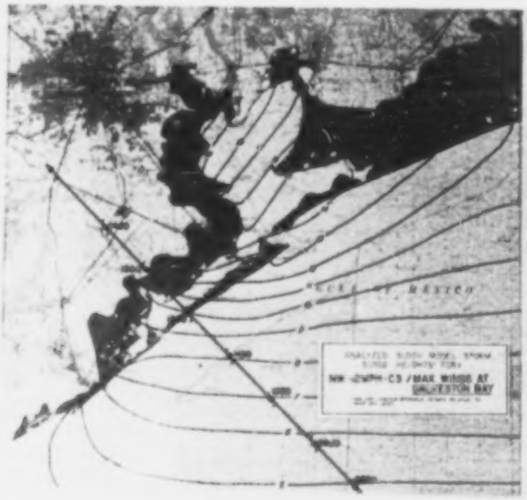
4. Coastal county populations for the state of Florida from 1900 to 1985.



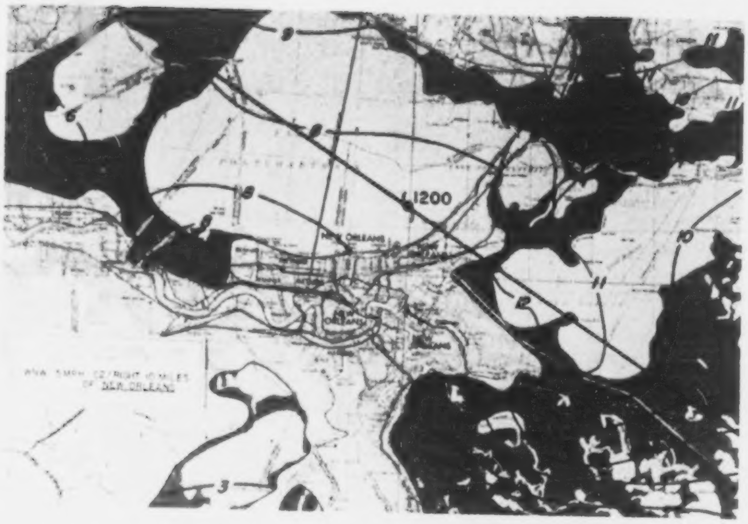
5. Coastal county populations for the states of Virginia, Delaware and New Jersey from 1900 to 1985.


GULF OF MEXICO
MAX WINDS AT
GALVESTON BAY

6. Galveston, Texas area inundation (green areas) produced by rising waters from a category two hurricane (Saffir/Simpson scale). Note maximum water rises of about 10 feet.


GULF OF MEXICO
C3 /MAX WINDS AT
GALVESTON BAY

7. Galveston, Texas area inundation (green areas) produced by rising waters from a category three hurricane. Note maximum water rises of about 14 feet on the coast and greater than 20 feet at the north end of Galveston Bay. More than 200,000 additional people would be affected by this strength of hurricane as compared to a category two hurricane.


9
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1200
NEW ORLEANS
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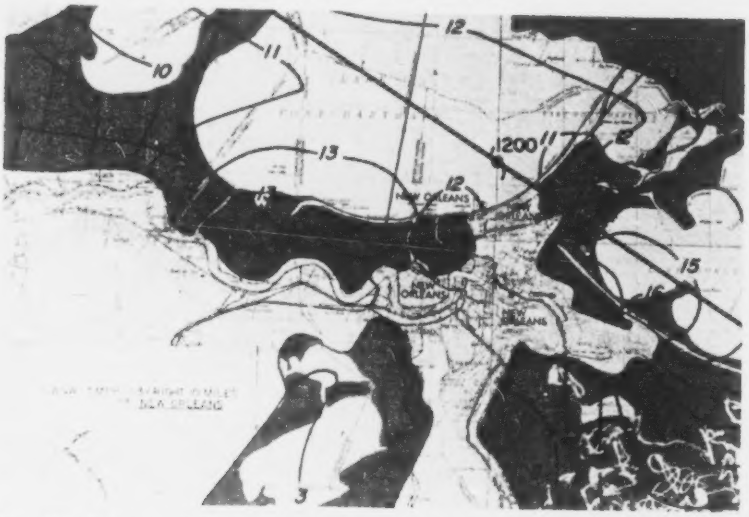
11
12
3

8. New Orleans, Louisiana area inundation (green areas) produced by rising waters from a category two hurricane (Saffir/Simpson scale). Note maximum water rises south of Lake Pontchartrain are about 8 feet with little flooding of New Orleans proper.


12
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1200
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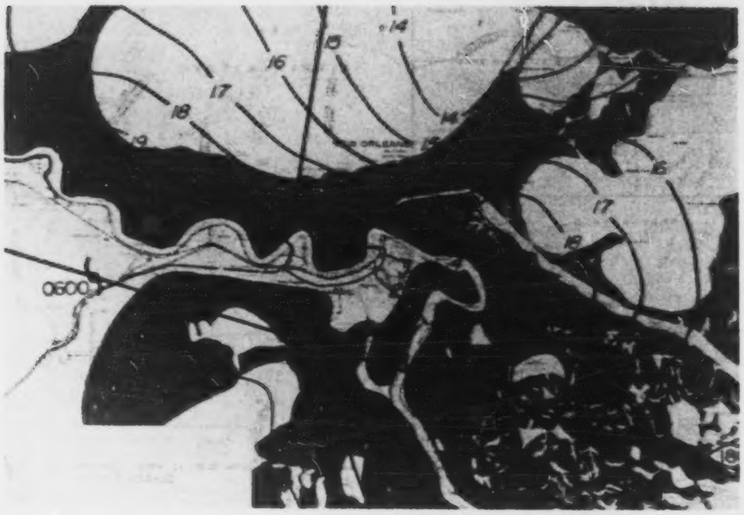
NEW ORLEANS
15
16
NEW ORLEANS
3

9. New Orleans, Louisiana area inundation (green areas) produced by rising waters from a category three hurricane. Note maximum water rises of about 13 feet south of Lake Pontchartrain and large portions of New Orleans proper are flooded.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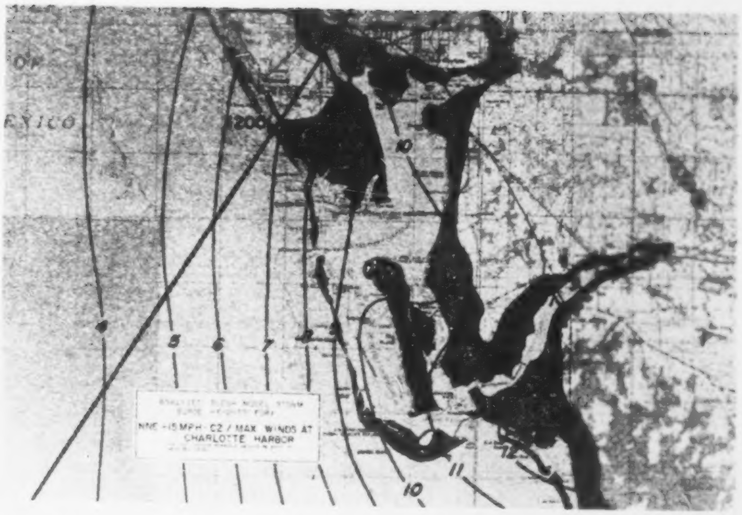
0600

10. New Orleans, Louisiana area inundation (green areas) produced by rising waters from a category four hurricane (Saffir/Simpson scale). Note maximum water levels south of Lake Pontchartrain of more than 18 feet with most of New Orleans under water!


OF
EXICO
1200
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NNE -15MPH- C2 / MAX. WINDS AT
CHARLOTTE HARBOR
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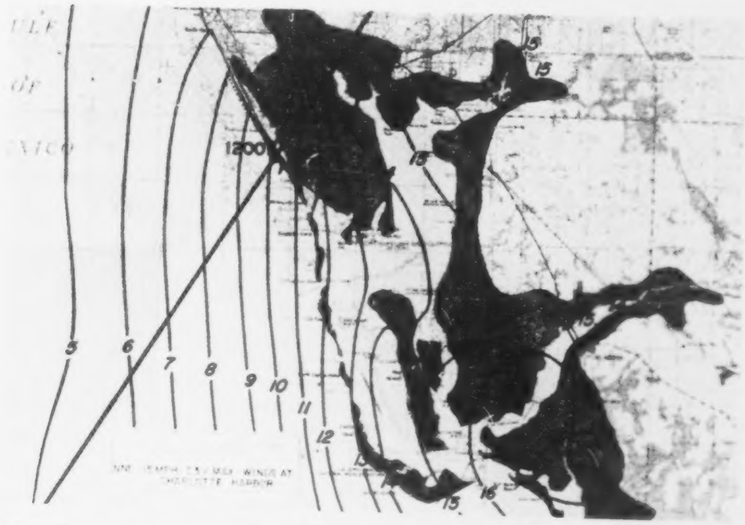
11
12

11. Ft. Myers, Florida area inundation (green areas) produced by rising waters from a category two hurricane (Saffir/Simpson scale). Note maximum water rises of about 12 feet.


ULF
OF
XICO
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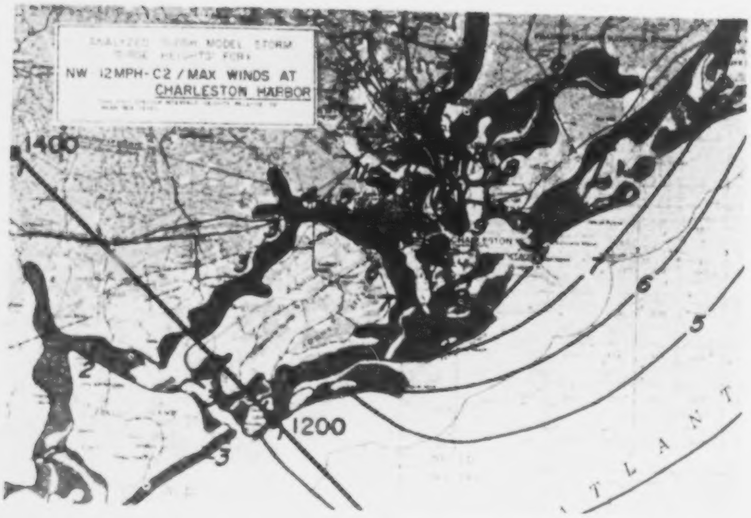
NNE 15MPH C3 / MAX. WINDS AT
CHARLOTTE HARBOR
13
14
15
16

12. Ft. Myers, Florida area inundation (green areas) produced by rising waters from a category three hurricane. Note maximum water rises of about 17 feet and the large additional areas and associated populations affected by this strength hurricane as compared to a category two hurricane.


ANALYZED SLOSH MODEL STORM
SURGE HEIGHTS FOR:
NW 12MPH-C2 / MAX WINDS AT
CHARLESTON HARBOR
1400
1200
CHARLESTON
6
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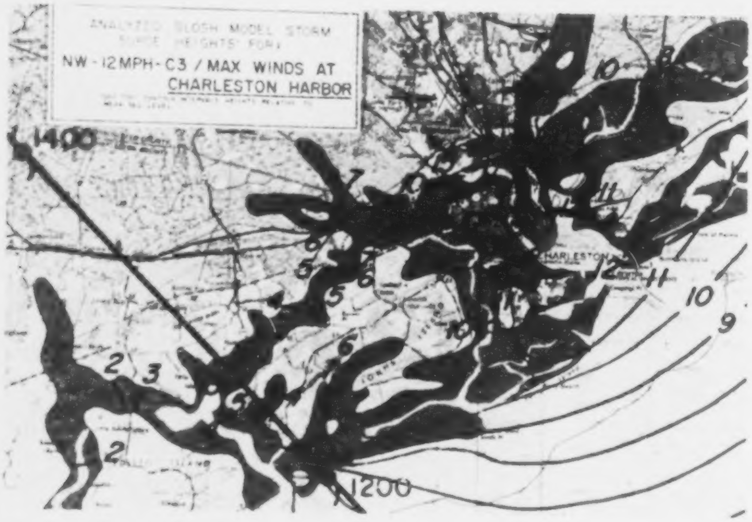
ATLANT

13. Charleston, South Carolina area inundation (green areas) produced by rising waters from a category two hurricane (Saffir/Simpson scale). Note maximum water rises of about 10 feet.


ANALYZED SLOSH MODEL STORM
SURGE HEIGHTS FOR:
NW-12MPH-C3 / MAX WINDS AT
CHARLESTON HARBOR
1400
1200
CHARLESTON
10
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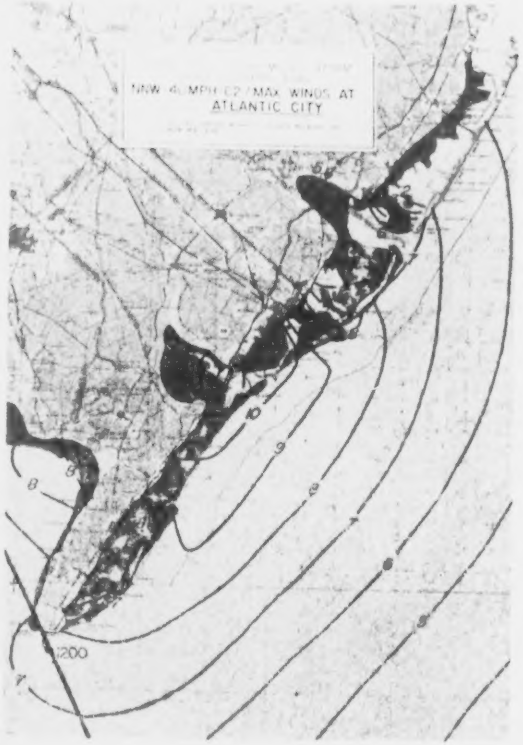
14. Charleston, South Carolina area inundation (green areas) produced by rising waters from a category three hurricane. Note maximum water rises of about 14 feet and the large additional areas and associated populations affected by this strength hurricane as compared to a category two hurricane.


NNW 40MPH C2 / MAX WINDS AT
ATLANTIC CITY
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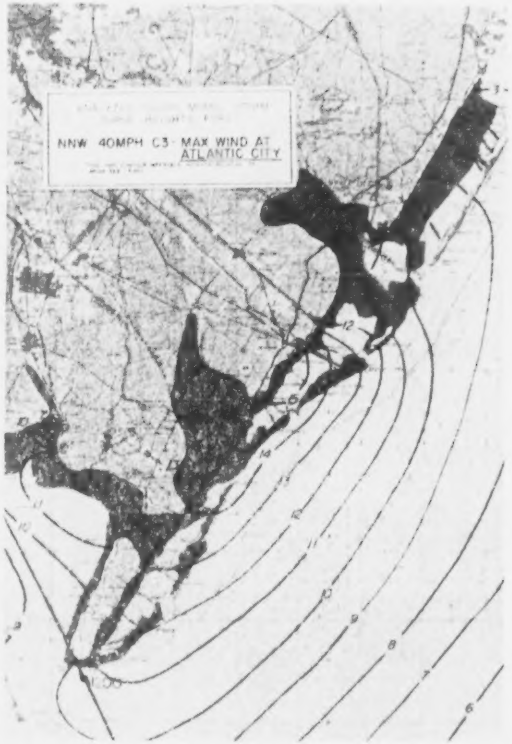
1200

15. Atlantic City, New Jersey area inundations produced by a category two hurricane (Saffir/Simpson scale). Note maximum water rises of about 10 feet at the coast.


NNW 40MPH C3 MAX WIND AT
ATLANTIC CITY
12
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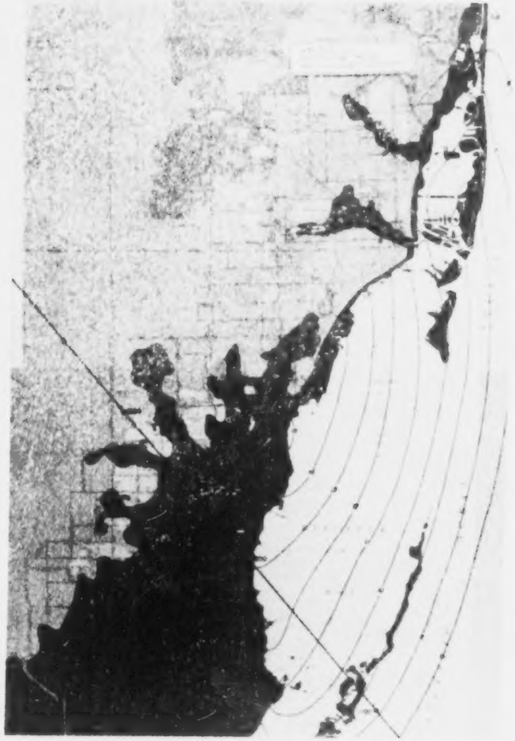
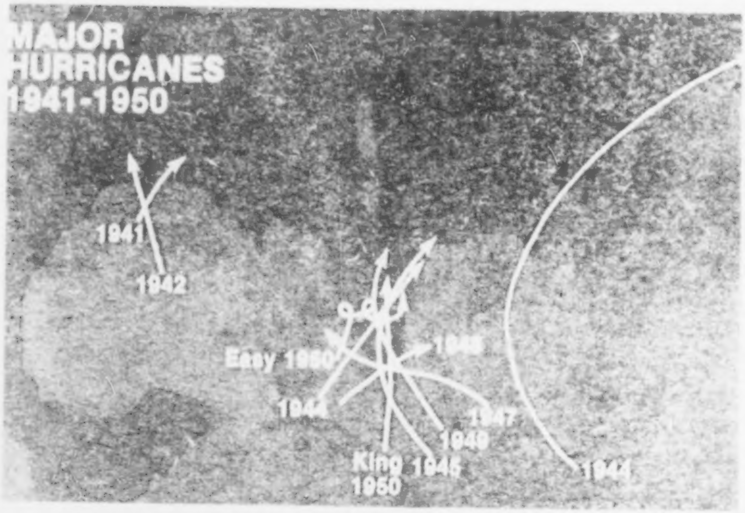
16. Atlantic City, New Jersey area inundations produced by a category three hurricane. Note maximum rises of 15 feet and resulting in Atlantic City proper being under water.

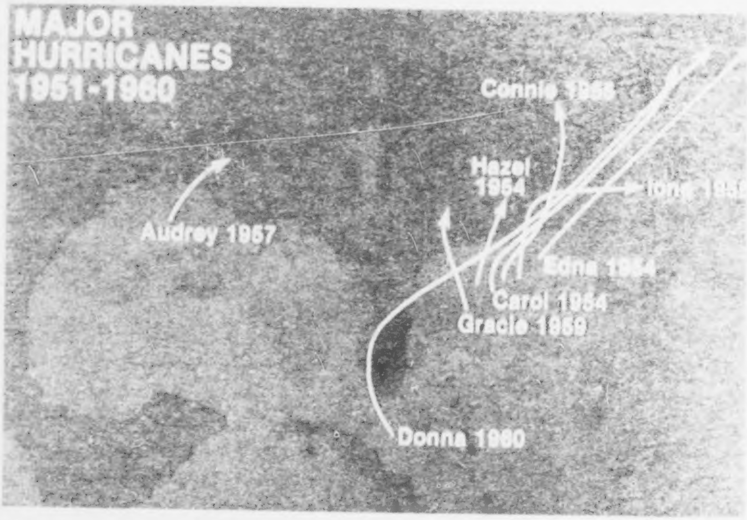
17. Satellite picture of hurricane Gilbert superimposed on southeast Florida. Note that if such a hurricane were to strike Florida, several million people would be affected at the same time (above).



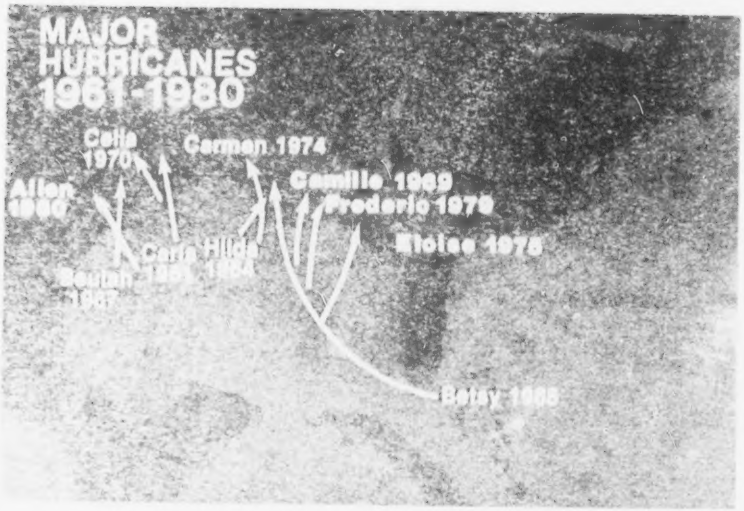
18. Predicted areas of inundation (green) for a Gilbert strength hurricane striking southeast Florida (right). Maximum water rises would be above 14 feet in south Dade county. Most of Key Biscayne and Miami Beach would be under water for this situation. If the track of the hurricane track (broad dark line) was displaced to the north a few miles, 12 to 14 feet water rises would be experienced along Miami Beach and northward.


MAJOR
HURRICANES
1941-1950
1941
1942
Easy 1950
1948
1944
1947
1949
King 1945
1950
1944

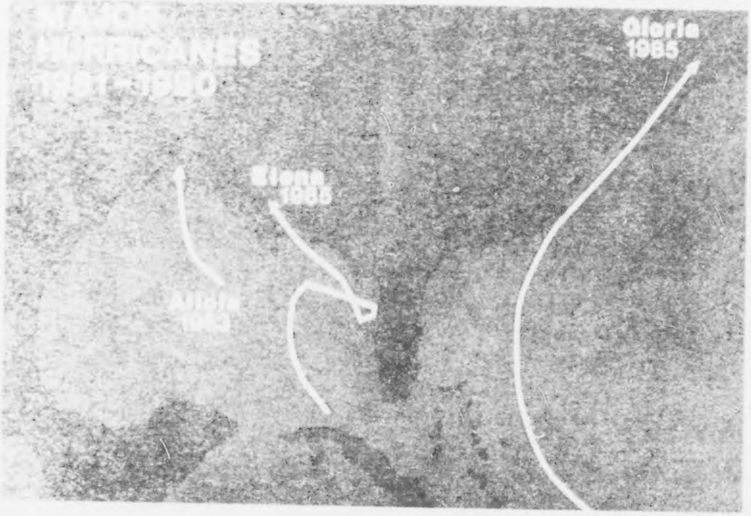
19. Tracks of major hurricanes (category three or stronger) striking the continental United States from 1941 through 1950.


MAJOR
HURRICANES
1951-1960
Connie 1955
Hazel
1954
Ione 195
Audrey 1957
Edna 1954
Carol 1954
Gracie 1959
Donna 1960

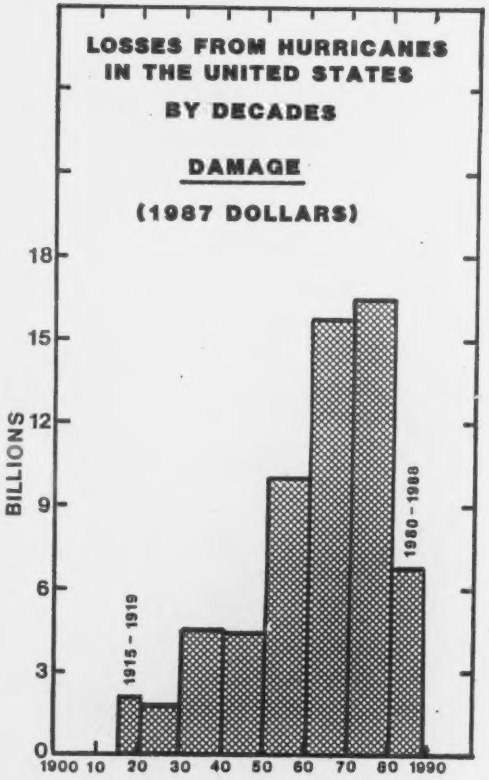
20. Tracks of major hurricanes (category three or stronger) striking the continental United States from 1951 through 1960.


MAJOR
HURRICANES
1961-1980
Celia 1970
Carmen 1974
Allen 1980
Camille 1969
Frederic 1979
Eloise 1975
Carla 1961
Hilda 1964
Beulah 1967
Betsy 1965

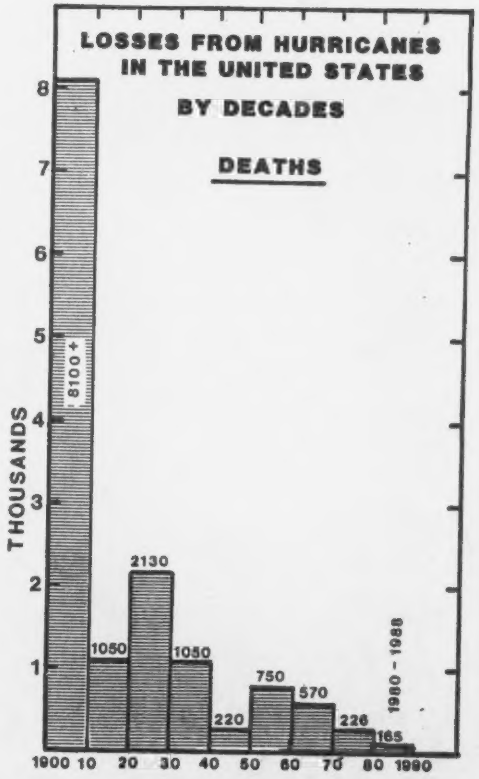
21. Tracks of major hurricanes (category three or stronger) striking the continental United States from 1961 through 1980.


MAJOR
HURRICANES
Gloria 1985
Elena 1985
Alicia 1983

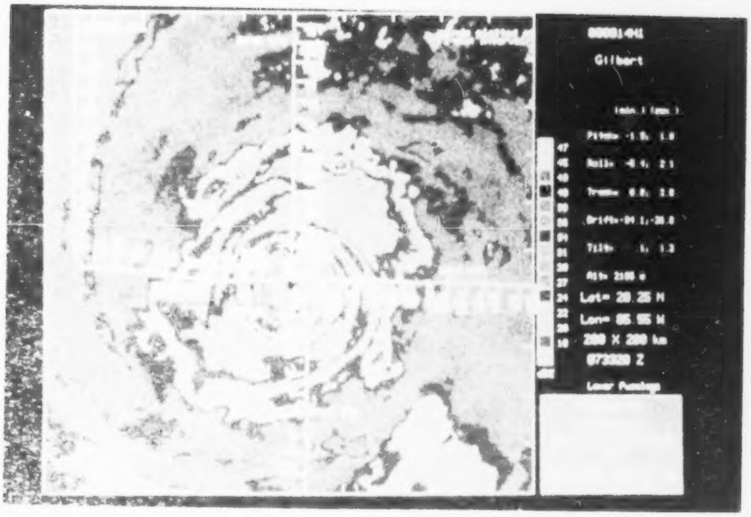
22. Tracks of major hurricanes (category three or stronger) striking the continental United States from 1981 through 1988.



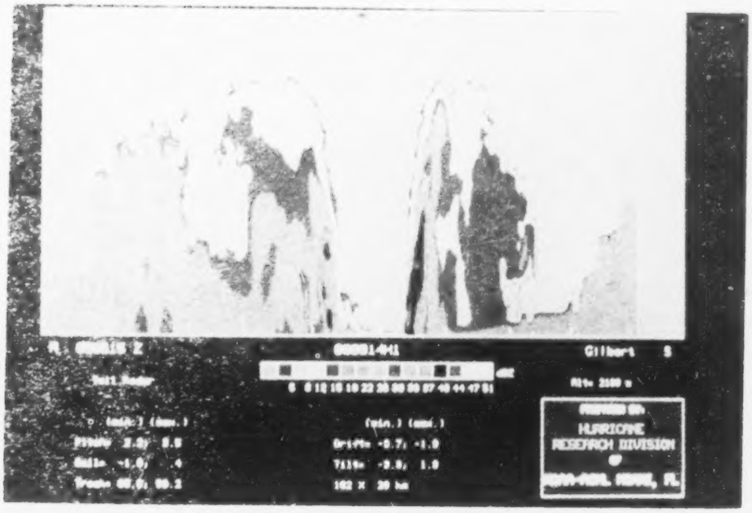
23. Direct damage by decade resulting from hurricanes striking the continental United States from 1915 through 1988. Losses have been adjusted to 1987 dollar values.



24. Deaths by decade resulting from hurricanes striking the continental United States from 1900 through 1988.



25. Hurricane Gilbert horizontal (Plan Position Indicator) radar image and flight level winds recorded onboard a NOAA research aircraft on September 14, 1988. Each flag represents 50 knots of wind. The maximum wind shown is 165 kts (190 mph). The minimum sea level pressure at this time was 890 mb (26.28 inches).



26. Hurricane Gilbert vertical cross section radar image (Range Height Indicator) recorded onboard a NOAA research aircraft at 4:06 a.m. EDT (0906 Z) on September 14, 1988. The colored dot in the center of the picture is the location of the aircraft in the "eye" with the vertical "eyewall" shown on either side of the aircraft.

THE SAFFIR/SIMPSON HURRICANE SCALE

Scale No. 1 - Winds of 74 to 95 miles per hour. Damage primarily to shrubbery, trees, foliage, and unanchored mobile homes. No real damage to other structures. Some damage to poorly constructed signs. And/or: storm surge 4 to 5 feet above normal. Low-lying coastal roads inundated, minor pier damage, some small craft in exposed anchorage torn from moorings.

Scale No. 2 - Winds of 96 to 110 miles per hour. Considerable damage to shrubbery and tree foliage; some trees blown down. Major damage to exposed mobile homes. Extensive damage to poorly constructed signs. Some damage to roofing materials of buildings; some window and door damage. No major damage to buildings. And/or: storm surge 6 to 8 feet above normal. Coastal roads and low-lying escape routes inland cut by rising water 2 to 4 hours before arrival of hurricane center. Considerable damage to piers. Marinas flooded. Small craft in unprotected anchorages torn from moorings. Evacuation of some shoreline residences and low-lying areas required.

Scale No. 3 - Winds of 111 to 130 miles per hour. Foliage torn from trees; large trees blown down. Practically all poorly constructed signs blown down. Some damage to roofing materials of buildings; some window and door damage. Some structural damage to small buildings. Mobile homes destroyed. And/or: storm surge 9 to 12 feet above normal. Serious flooding at coast and many smaller structures near coast destroyed: larger structures near coast damaged by battering waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Flat terrain 5 feet or less above sea level flooded inland 8 miles or more. Evacuation of low-lying residences within several blocks of shoreline possibly required.

Scale No. 4 - Winds of 131 to 155 miles per hour. Shrubs and trees blown down; all signs down. Extensive damage to roofing materials, windows and doors. Complete failure of roofs on many small residences. Complete destruction of mobile homes. And/or: storm surge 13 to 18 feet above normal. Flat terrain 10 feet or less above sea level flooded inland as far as 6 miles. Major damage to lower floors of structures near shore due to flooding and battering by waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Major erosion of beaches. Massive evacuation of all residences within 500 yards of shore possibly required, and of single-story residences on low ground within 2 miles of shore.

Scale No. 5 - Winds greater than 155 miles per hour. Shrubs and trees blown down; considerable damage to roofs of buildings; all signs down. Very severe and extensive damage to windows and doors. Complete failure of roofs on many residences and industrial buildings. Extensive shattering of glass in windows and doors. Some complete building failures. Small buildings overturned or blown away. Complete destruction of mobile homes. And/or: storm surge greater than 18 feet above normal. Major damage to lower floors of all structures less than 15 feet above sea level within 500 yards of shore. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Massive evacuation of residential areas on low ground within 5 to 10 miles of shore possibly required.

Mr. LEWIS. Thank you, Dr. Sheets, for a great presentation. Some of these things are horrifying.

Mr. SCHEUER. A lot of the things are horrifying. I am grateful for your marvelous testimony.

Can you tell us what are the components of this $50 million bill? It seems to me as an uninformed layman that just getting out a warning, you call the radio stations, you call the television stations, you call the newspapers, and then you call the police and fire department, hospitals, you know a couple dozen phone calls and that is it. How can you spend $50 million?

Dr. SHEETS. We do not spend the $50 million, the people preparing for the hurricane spend the $50 million, the people along the coastline. You have to close down the Florida Power & Light facilities along the coast, or Amoco Oil Company or the individual homeowner who has to go and shutter up their home. So that is the expense, not the expense of the National Hurricane Center or National Weather Service.

Mr. SCHEUER. Does that count the losses to the casinos for closing?

Dr. SHEETS. It does not include losses, it is just the preparation costs. For instance, with the casinos, there would be many, many millions more than that. Or in the case of hurricane Elena that struck the Gulf coast, the Florida panhandle region on the Riviera of the South as it is called, Gulf Shores, Alabama and that area, it occurred on Labor Day weekend. Now take Labor Day weekend away from a high tourist area, and particularly that area or Padre Island or anyplace up the east coast. In this case it was 1/17th of their entire income for the year, just for that one morning. So it is much larger numbers under particular situations.

Mr. SCHEUER. Just one more question. I take it you feel it is negligent for some communities not to have the kind of building codes that would minimize the damage from a hurricane.

Dr. SHEETS. Well let me put it this way. I do not think we all ought to be paying for it, and we all are paying for that. If the individual paid for whatever they put up there, but we should not have everybody else pay for that. And indeed, our building codes as we have in south Florida, make it safer for the residents, make it easier for some of us emergency management people that have to deal with protection of those lives and property and we think those are the kinds of codes that ought to exist along our hurricane prone areas.

Mr. SCHEUER. Now how do the rest of us pay for it when a particular community is negligent and do not have the kind of building codes in place that would reduce damage from a serious hurricane to a minimum. How do the rest of us pay for it?

Dr. SHEETS. Well several ways. One is insurance. Basically insurance has to get prorated in many ways and I understand in Texas after hurricane Elena, the insurance companies wanted to pull out of insuring at all along the coast. And there they ended up having to go into sort of a high-risk kind of a pool for insuring there, but the risk really gets spread out. There are re-insurance programs and when someone sells you an insurance policy on the coast over here, whoever that particular person is, he really does not hold that for the entire risk. It gets sold again and sold again and you spread that risk over the world, not just within the United States.

In Federal subsidies that go back to prepare and rebuild Gulf Shores, Alabama after it was destroyed by hurricane Frederick or in Dauphin Island, Alabama or in Galveston area, the Federal subsidies that go back. The insurance premiums that go up. That is how we pay for it.

Mr. SCHEUER. Yes. How about the Federal flood insurance programs. Can you describe the connection between the failure of a community to put in place adequate building codes and the cost of money in the Federal floor insurance program?

Dr. SHEETS. I understand that the Federal flood insurance program is now the second highest amount of money compared to—next to social security, I believe that is the numbers that I heard. It is very large numbers that have gone into that program in trying to make it self-sustaining, and so the rates are going up on the coast and maybe being reduced somewhere else, a little bit back end. But indeed there are very large expenses associated with that and it had to be subsidized for sometime, but there is an attempt to make it self-sustaining.

Mr. SCHEUER. Make the Federal flood insurance program self-sustaining?

Dr. SHEETS. That is correct.

Mr. SCHEUER. I do not know how they could do that because you have got people in the coastal regions taking the policies, you know. After their mother's milk they sign up for Federal flood insurance, but the people inland would not need to do that.

Dr. SHEETS. As you go to the future, what has happened under the Federal flood insurance program, as new buildings are built they must be built to certain levels. Now the building code itself may still be a little bit weak, but at least the level you build to where you may have a flooding problem, then you build to a little bit higher level and so you have less and less of a risk. The problem is—

Mr. SCHEUER. What would require developers to build to higher levels if the building codes do not?

Dr. SHEETS. That really has to be a building code problem. The flood insurance does require that you have to build to a certain level but there are so many out there who are grandfathered in already, and so indeed if we had an outbreak of the hurricanes of the 1940s and 1950s that we showed you there, the flood insurance program would certainly not be self-sustaining because there would be major losses that would have to be caught up into the future.

Mr. SCHEUER. For existing buildings that you say have been grandfathered in and do not comply with a modern code even if it was put into place after that was built, is there anything you could do now, for the average of these buildings, to retrofit them, to put them to withstand the incredible force of a major hurricane?

Dr. SHEETS. I am really not an expert in the engineering aspects of that ability. My personal feeling is it would probably be nearly prohibitive in cost to retrofit. So we need to go—I think the more appropriate way to go is to go in the future and make those fairly strong and build to a much higher level.

Mr. SCHEUER. All right, I have a last question—this really is the last question.

What would you think of a national policy that would say in effect, look, if you want to build a building that is not in compliance with modern standards and codes, you can do it, but do not expect to get Federal flood insurance. Any community that does not have rigorous—any coastal community that does not have the state-of-the-art level of code, building requirements, will not be eligible for Federal flood insurance.

Dr. SHEETS. I believe that is in a sense in effect, but the Federal flood insurance program requires you build to a certain elevation, and flood insurance only pays off for water. Anything above that is a wind policy, and the code is more of a problem in the wind policy area. Now as far as the flood problem, it is a problem in where we build. In other words, building down on the water itself, and certainly setback lines being enforced would be very beneficial in that area.

Mr. SCHEUER. Well that is part of the local code, is it not?

Dr. SHEETS. Yes, but also Federal codes in terms of barrier islands and where you build and there is a lot of legislation in those areas. I am not really well-acquainted with all of those aspects of the Federal legislation.

Mr. SCHEUER. To your knowledge, you do not see any particular move for tightening up those regulations and providing some powerful incentives for communities all along the length and breadth of our coastal areas to put in place these codes, these codes with high standards?

Dr. SHEETS. I would certainly like to see that take place with appropriate setback lines. What usually happens is that we get started on some of those things and then there are special interests that come in for economic reasons that want to dilute those kinds of things, and then you go back and build a little bit closer and build to a little bit lower standards. Even here in our building codes that we have in south Florida, if you go back to the 1940s and 1950s after all those hurricanes, the way the code came about was basically the hurricane came along and blew down your house and you looked and said let us put a strap there on this particular stud the next time. It came along the next year and blew it down again and they said let us put a strap on every other stud and then the third year it was knocked down, let us put it on each stud. And that is the process that is going on today in Galveston for instance. That is what happened there, Alicia came along and the hurricane clips were used, they came apart, and now they use a strap on every fourth stud. Well two more hurricanes it will probably be on every other stud. But let us do not learn by these experiences, let us learn from these experiences that we have had here and let us apply that everywhere.

Mr. SCHEUER. That is a pretty expensive lesson for the taxpayer.

Dr. SHEETS. Very much so. We pay it either in taxes or insurance premiums.

Mr. SCHEUER. Pay now or pay later. Thank you very much.

Mr. LEWIS. Thank you, Mr. Chairman. The gentleman from Wisconsin, Mr. Sensenbrenner.

Mr. SENSENBRENNER. Thank you very much, Dr. Sheets for some very interesting and enlightening testimony. I would like to ask two lines of questions if I could, Mr. Chairman. First of all let me ask about your credibility and that of the news media because obviously the people have to believe these warnings if they are to evacuate the areas that have to be evacuated. What problems have you had and have news media meteorologists taken your data and ad libbed and frequently given people the wrong impression, and if so, can you give us a couple of examples?

Dr. SHEETS. You are really putting me on the spot.

Well indeed it is a problem in terms of having the credibility to do things. And I think this morning's session of the National Hurricane Conference highlighted that. We are fortunate, and not because it is Bob Sheets, but the National Hurricane Center does have a very high level of credibility. And again I have only been there two years, so I have not had time to destroy it yet. But anyway, we have a fairly high level of credibility and so indeed that does take place. But confusion can be a problem, conflicting kind of information that goes out to the community. And one of the things that was highlighted at our conference this morning was the conflicting information that went into the Galveston-Houston area. The media, as far as the National Hurricane Center is concerned, is part of the warning process. It is not a news story that we are dealing with, it is a warning process. And indeed the great majority of the media who work out of the National Hurricane Center and along our coastlines work with us. They recognize their responsibility in those areas. It is the ones who are uninformed, the new person who just came down from Wisconsin to the Gulf coast or something. He has been up there and really does not know about hurricanes very well and then steps out and says that the hurricane is going to go to Galveston when the National Weather Service said it was going to Brownsville. And the end result is another 20-30,000 people then panic and start doing all kinds of things.

We had that problem with hurricane Gilbert. The City Manager of Galveston relayed that information and related that to us this morning in our conference. So conflicting information is a problem.

I think a good analogy of the way things ought to work, and perhaps there is legislation that could go to these areas, but the way things ought to work is similar to a school system. In other words, in a school system you set out that classroom A has to move out before classroom B, and classroom C follows B and they go down certain hallways to get out. And then within the classroom, you have row one, row two, row three, and they all have to follow each other out. And you have a very complicated kind of process to get people out in the minimum amount of time.

The evacuation problem as you see on those maps there is identical to that. If you leave Galveston Island, you have got to go in on certain roadways through other communities which have to be monitored, and all monitored and checked. That is the reason all these maps were done and all these analyses were done, and comprehensive evacuation studies were done. If somebody comes in and says everybody out over here—for instance, if everyone came into the school room at one stage and said "fire, everybody out", you would have chaos and you would probably lose lives. The same thing is going to happen here with our hurricane evacuation programs. It is similar to that.

We have a Federal system that is the National Weather Service which has the statutory responsibility for providing these forecasts and warnings for hurricane and other severe weather events. We have those same statutory responsibilities for state and local officials for protection of lives. We spend years working with local officials, state officials, doing the kind of studies that I showed you there. We go through the fire drills so to speak, like the school does, and we optimize all these things. But when somebody comes in and throws in a confusing piece of information like it is going to Galveston, everybody ought to be out, then indeed you have got a problem.

Mr. SENSENBRENNER. Does the fire drill include bringing all the news media in so you do not have an ignoramus sitting behind a microphone broadcasting erroneous information out to the people?

Dr. SHEETS. Well there is always some problem like that, just as there is among National Weather Service local officials or whatever. There are new people all the time coming into these areas. The great majority of the news media do an excellent job. They do a good job, they work with you. In fact, one of the news media got an award today as a result of some of the work they had done. They will be testifying here later. But indeed that kind of thing works very well. It is the new person that gives you the problems. The news media themselves, actually within the National Hurricane Center, they monitor each other and help each other and it is a non-competitive situation, and that is the way it ought to be treated across the board. A non-competitive situation, a responsibility that they have and a part of that warning process.

Mr. SENSENBRENNER. My second line of questioning involves the impact of the failure of the GOES satellite. It is obvious that we are going to have to do with one of them for the next two fiscal years because it will not be until 1990 if all goes well that the new one will be put up. What impact is moving the GOES satellite west of the central part of the U.S. had in terms of actual accuracy where a hurricane goes ashore and what its intensity would be, since you lose a couple of days by not being able to check it when it is developing off the coast of Africa?

Dr. SHEETS. Well first I want to make a statement right up front. A lot of people know that I have been certainly adamant about the need for reconnaissance aircraft. I have made that very clear. If I had only one observing tool available to me, it would be the GOES satellite. It is the most important piece of information that I have available to me for the tropical forecast of any country—no question, it is the best, and the single most important one.

The one GOES satellite we have just two or three weeks ago went out for six hours. Panic. There is nothing, we are not seeing. We are used to seeing these things every 30 minutes coming off of the machine and everyone was so concerned that this meant that there was some major failure with the one satellite. It turned out to be a ground problem and we are very fortunate about that. But indeed it is a tenuous situation that we are dealing with the GOES satellite.

The one satellite situation means that we cover the Gulf of Mexico and the east coast fairly well up until you get to higher latitudes, up off Maine and so on that is getting more towards the fringe areas. We cover those areas fairly well. We do not get a very good look down into the Lesser Antilles, for instance, and Windward Islands and down in those areas. It is around the curve there a little bit. So not a very good look over there. Or over in Hawaii or up towards Alaska. This is a problem and areas that we cannot see from there.

Mr. SCHEUER. Or over to west Africa.

Dr. SHEETS. We cannot see that at all from this particular satellite. Now we try to use other means to compensate for that. And I use the word compensate because no way we could replace the need for the two satellite system. You are, I am sure, well aware of the scenario that got us into this situation where one failed early and another one was blown up on launch, which was basically our spare situation. So that is what got us into the condition that we are in right now.

How do we compensate? During the hurricane season we move that satellite about 10 degrees farther to the east than we do during the winter season. Winter season, most of the weather comes off of the Gulf of Alaska and so we have got to cover that area for the west coast of the United States. During the summer season, the hurricane season, we need to get a little bit more off of the east coast. We also have a satellite from Europe that is called METEOSAT that covers the African region but it is not directly fed back in to us. We are working on getting some of that information fed directly in to us and we expect to have that at the Hurricane Center but there are still gaps in between. We have polar orbiting satellites but that is like getting a Polaroid picture as compared to a videotape or a moving or whatever. The Polaroid gets you a snapshot every six hours or every 12 hours from any given satellite there, polar orbiting satellite. So it is snapshots there. So we try to compensate and what we did in the past when we had this same situation in 1983 with—in 1984, when we had one satellite. Then we used more reconnaissance aircraft. When we see systems coming into the island, then we place airplanes down at Antigua to intercept this third weather area. We could see them on the fringe of the satellite but we cannot make very accurate kind of estimates of what is going on there. So we used aircraft more frequently than we normally would.

Mr. SENSENBRENNER. Thank you.

Mr. LEWIS. Thank you, Mr. Sensenbrenner.

Dr. Sheets, if today's hurricane forecasting technology is no better than the 1960s, if it is, despite billions of dollars being spent, how can the accuracy be improved?

Dr. SHEETS. We are improving slowly. People expect some major leap. When is the next breakthrough? Well meteorology does not work that way, it is like a lot of other things. There is no quick cure that you have the development of a new vaccine and all of a sudden you cure it. It is a slow process. We are improving about 1 percent per year. So from the 1960s to the present time, that is a slow improvement, 20 percent is a lot of improvement when you look at it in that sense. Much slower than we would like. As I showed you, the population has grown much faster than 1 percent per year. So it is an offsetting kind of problem that we have.

How can we improve it in the future? I personally am an optimist. I guess most people that know me know that I am an optimist. So I expect that we are going to improve and I think we are going to—our rate of improvement is going to increase over the next five to ten years because of the new technology we have coming along, the new GOES-NEXT that you will hear more about here a little bit later. The new IWRS systems, the new Air Force systems on board the aircraft that we will have available to us this year. The new Doppler radars that are going to be along our coast. Now those help close to the coast, they do not help out away from land. But all of those things I think indeed are going to improve our forecasts. We have a new major computer that is planned to be at the National Meteorological Center, a Class 7 computer we talk about, to predict out into the future when we look at 36, 48, 72 hours, it is highly dependent on that large computer model and the information that is fed into it from the surrounding atmosphere that needs to go into that model.

I am optimistic that indeed we will improve our forecasts out there. However, those statistics that we just looked at say that our population and the problem is going to grow faster than our rate of improvement.

Mr. LEWIS. I want to go back to a question that Mr. Sensenbrenner asked on the GOES satellite. Depending upon where you are in Florida, it takes a maximum evacuation in certain areas up to 22 hours to get people off.

Dr. SHEETS. Yes, sir.

Mr. LEWIS. Looking at a 3, 4, 5 storm, from a minimum to a maximum evacuation with only one GOES satellite currently available, will we have a shorter notification to the people of Florida because of this?

Dr. SHEETS. I would think not. Now what we will do, again, the way we are going to compensate for that, we are going to have to fly more. We are going to have to use those reconnaissance aircraft more especially out to the east of here, than we have used in the past. So those are the ways we are going to have to compensate.

What we do with satellite and recon is we intermix. In other words, with the satellite we infer certain conditions. And again, it is the most important tool that we have, the most important observing tool. But it does not have the ability to tell me whether it is a category two or a category three with a degree of certainty. That is what the airplane does.

So what we do is we look at it from the satellite, we fly the airplane in there and calibrate, calibrate the satellite estimate that is there. Then we may miss 6, 8 hours, 10, maybe even 12 hours, maybe even longer, maybe 24 hours. We do that when we are well out over water and then we come back—and we rely totally on the satellite during that period. Then we come back with the airplane and calibrate it again and redo that. Then as we get closer to land, we cannot afford these long periods of calibration in between here, so we fly more airplanes during that period. But as far as the people of Florida are concerned, and hopefully the GOES satellite will stay there and operational for us, it tells us where the fires are and we need to send the airplanes out to get us the details on that. We do not expect any deterioration in our forecast abilities for this area.

Mr. LEWIS. Well that is certainly good news.

Dr. Sheets, I saw a picture of you this morning, a young Bob Sheets, and you still have color to your hair even today and that was quite awhile ago in a hurricane plane. So you are hanging together pretty good in a very tenuous position.

I thank you very much for the work that you do and thank you on behalf of the people of Florida because I think you do an outstanding job. I know you have had a long couple of days and I am not going to ask you any more questions unless the panel has further questions. Do staff members have questions they would like to ask Dr. Sheets?

[No response.]

Mr. LEWIS. Thank you, Dr. Sheets.

Dr. SHEETS. Thank you.

Mr. LEWIS. We may have some questions, Dr. Sheets, that may come up and we would like you to respond in writing if you would.

Dr. SHEETS. Surely.

Mr. LEWIS. I would like to ask our next panel please, for hurricane surveillance. Col. Jerry Riley with the Air Weather Services, U.S. Air Force; Russell Koffler, Deputy Assistant Administrator for the National Environmental Satellite, Data and Information Service and Fred Stang, Director of Business Development Space Systems Division for Ford Aerospace.

Your entire written statements will be placed in the hearing record and you could take a few minutes to summarize your testimony, the Subcommittee would appreciate it.

STATEMENTS OF LT. COL. JERRY RILEY, AIR WEATHER SERVICES, U.S. AIR FORCE; RUSSELL KOFFLER, DEPUTY ASSISTANT ADMINISTRATOR, NATIONAL ENVIRONMENTAL SATELLITE, DATA AND INFORMATION SERVICE AND FRED STANG, DIRECTOR OF BUSINESS DEVELOPMENT, SPACE SYSTEMS DIVISION, FORD AEROSPACE

Colonel RILEY. Thank you, Congressman Lewis. I am Jerry Riley. I do not have any opening statement. I will be happy to answer any questions that anybody has.

Mr. LEWIS. Okay, that will get you off the hook then. Mr. Koffler.

Mr. KOFFLER. Thank you very much, Mr. Chairman. I am Mr. Koffler, Deputy Assistant Administrator for Satellite and Information Services at NOAA, and it is my job to provide the states space observations of the weather for the civilian government part. I have a short excerpt of my statement I would like to read and then we can hopefully move on in that regard.

The GOES satellites serve two functions for tropical weather forecasting. First, they provide images of clouds around the clock allowing forecasters to detect the earliest signature in a cloud and atmospheric moisture fields that point to tropical storm development. Second, they provide a capability to sound, if you would, the vertical temperature profiles of the atmosphere over broad areas where weather balloons cannot be launched, especially over the oceans.

As you have heard today, the current operational satellite is the GOES-7 satellite. It was launched in February, 1987. Its expected lifetime is five years and without any problems we should have that in place until 1992. This is the last of a series of the previous generation satellites that were capable of only taking imagery or soundings alternately and not at the same time. And we will talk a little bit more about that capability in the new spacecraft. It is currently now over 108 degrees west and it will be moved in June to 98 degrees west in order to position itself for the Atlantic hurricane season.

The single GOES coverage contingency plan also calls for supplementing that GOES-7 geostationary coverage with imagery from the two civilian polar orbiting satellites. These satellites can provide imagery about four times a day. Again, not nearly as much as the 48 times a day that the GOES satellite provides in terms of continuous coverage.

We also will continue to distribute, as Bob was saying, the METEOSAT data. We intend to upgrade the capability down at the National Hurricane Center for receiving high resolution data from the European satellite to give us a better look over the eastern Atlantic.

We also intend to upgrade the NOAA reconnaissance capability during the year, in terms of flying additional hours for hurricane recon during the season.

The first in the series of the next GOES satellites is scheduled to be launched next summer. It represents a new technology in geostationary weather satellite imaging. It is a three-axis stabilized spacecraft and Mr. Stang will talk some more about that. It allows us to operate the imaging and sounding capabilities simultaneously without sacrificing one or the other. The resolution of the sounders and the images are also going to be better, and the ability to accurately locate the significant weather features, i.e., where the hurricanes are, will also be enhanced.

In conclusion, the satellites have been the hurricane surveillance workhorses since the mid-1970s. While we are currently in a one GOES configuration, plans are in place for providing supplementary imagery from other spacecraft and we are looking forward in the summer of next year to launch of the GOES-I satellite to bring us once again to what we consider to be a fully operational two GOES weather satellite system.

Thank you very much for this opportunity to review the GOES weather satellite system.

Mr. LEWIS. Thank you, Mr. Koffler. Mr. Stang.

[The prepared statement of Mr. Koffler follows:]

TESTIMONY OF
RUSSELL KOFFLER
DEPUTY ASSISTANT ADMINISTRATOR FOR SATELLITE AND INFORMATION SERVICES
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

BEFORE THE

SUBCOMMITTEE ON NATURAL RESOURCES, AGRICULTURE RESEARCH AND ENVIRONMENT
HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

APRIL 7, 1989

Mr. Chairman, my name is Russell Koffler, Deputy Assistant Administrator for Satellite and Information Services, National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce. Thank you for the opportunity to address the status of NOAA's weather satellites for hurricane reconnaissance.

NOAA's Geostationary Operational Environmental Satellites (GOES) have provided uninterrupted coverage of the tropical oceans surrounding North America since the first prototype GOES flew in 1974. Forecasters rely on GOES imagery to watch for the earliest signs of tropical storm formation; to follow the development, intensification, and movement of hurricanes; and to estimate their rainfall potential.

Consider this Nation's deadliest natural disaster: In the year 1900, a hurricane crashed onshore at Galveston Island, Texas. Within hours of landfall, the storm's tidal surge had inundated the island and killed 6000 people. By the time its fury was spent, the storm had claimed over 12,000 lives. The only prior warning about the hurricane came in the form of a few scattered ship reports many days earlier. With GOES satellites scanning every mile of the tropical Atlantic Ocean, there never has to be another Galveston 1900, again.

Since 1900, our observing systems have come a long way, but are still clearly limited in the tropical oceans. Very few ship and island observations, and still fewer buoy reports, are available to provide the ground truth for all meteorological analyses in the tropics. The oceans are massive data voids. Only space-based observations, such as those made every half-hour from GOES, can adequately fill in the enormous gaps.

The GOES satellites serve two functions for tropical weather forecasters. First, they provide images of clouds around the clock, allowing forecasters to detect the earliest signatures in the cloud and atmospheric moisture fields that point to tropical storm development. Second, they provide vertical temperature profiles of the atmosphere over broad areas where weather balloons cannot be launched to do so.

Our current operational GOES satellite is GOES-7. It was launched in February 1987, with an expected lifetime of five years. This satellite is the last in a series of spin-stabilized GOES spacecraft that can either take images or soundings of the atmosphere in series. GOES-7 was recently moved to a central U.S. position to compensate for the loss of the western GOES-6 satellite, which failed on January 23, 1989, after 5 and one-half years of yeoman service. GOES-7 is now positioned at 108 degrees west longitude to better view winter-season storms on the Pacific coast. It will be moved to 98 degrees west in June to provide a better view of the tropical Atlantic and the Caribbean for hurricane season.

NOAA is currently without any back-up geostationary satellite due to the premature demise of the GOES-5 spacecraft in July 1984, and the destruction on launch of its replacement, GOES-G, due to a booster rocket failure in May 1986.

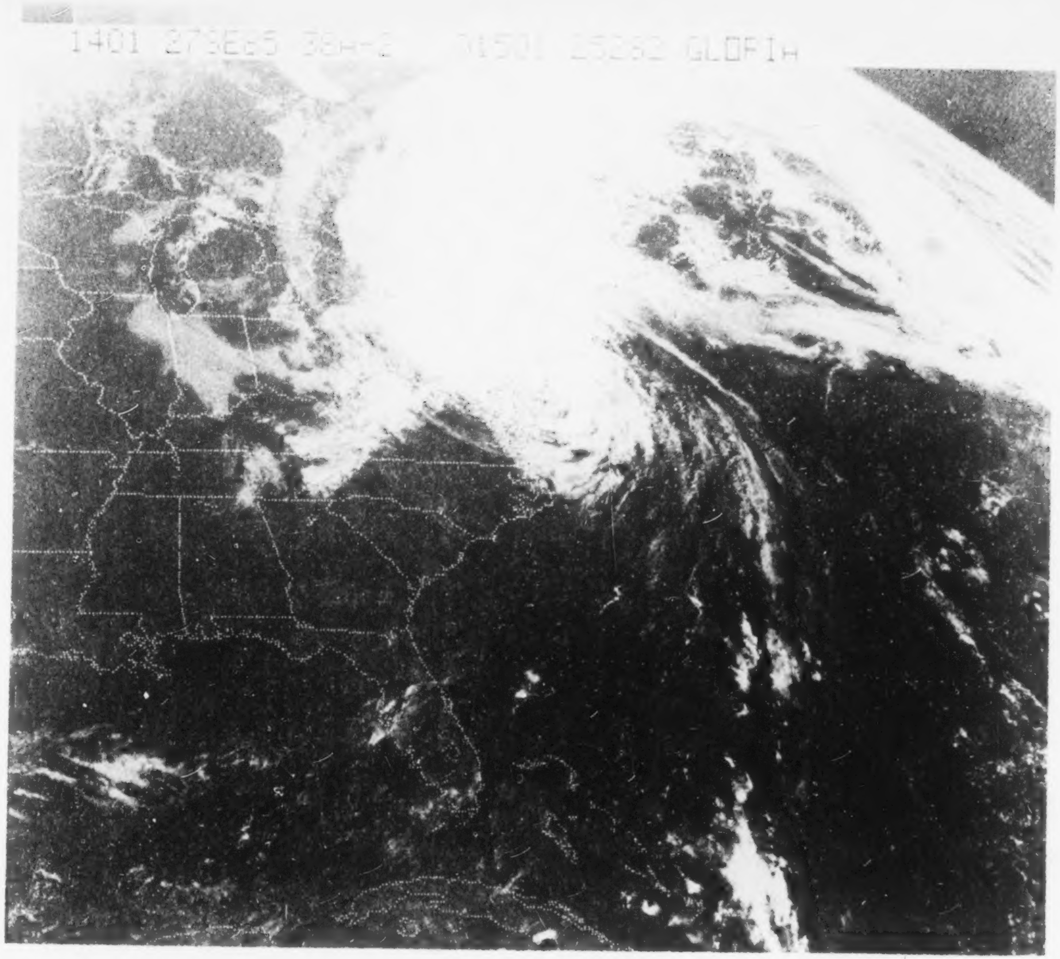
Our single-GOES coverage contingency plans call for supplementing the GOES-7 data with imagery from our polar-orbiting satellites. This polar-orbiter imagery can provide a twice-daily view of suspect areas in the tropical Atlantic and Pacific. We will also continue to distribute low-resolution imagery taken by the European Space Agency's METEOSAT geostationary satellite to the National Hurricane Center. The METEOSAT data provides much-needed coverage of the eastern Atlantic off Africa, where many hurricanes that eventually make U.S. landfall first begin to form.

The first in our next series of GOES satellites, GOES-I, will not be available for launch until summer 1990. The GOES I-M satellites represent a new technology in geostationary weather satellite imaging systems. The spacecraft is three-axis stabilized, not spin stabilized. The imager and the atmospheric sounder will operate independently and concurrently, allowing tropical weather analysts to better estimate the three dimensional thermal structure of the atmosphere surrounding a developing storm using GOES soundings, without sacrificing imagery of the storm clouds. The resolution of the sounder and the infrared imager will be better. The new system will also offer more flexibility to researchers who would otherwise have to interrupt operational satellite images for frequent, non-routine views over a limited geographic area.

If the last remaining operational GOES satellite were to fail, our Nation's hurricane early warning system would be dealt a serious blow. Polar-orbiting satellites provide only two views per day, with a one-to-two hour image-processing delay (compared to instant availability of GOES images). METEOSAT and the Japanese Geostationary Meteorological Satellite (GMS) do not provide any coverage over North America or its neighboring oceans.

Aircraft reconnaissance would be required far more frequently in a "no-GOES" operating scenario.

In conclusion, NOAA's satellites have been hurricane surveillance workhorses since the mid-1970s. While NOAA is currently in a one-GOES configuration, plans are in place for providing supplemental imagery from other spacecraft. We are looking forward to the summer 1990 launch of the GOES-I satellite to bring us once again to a fully operational two-GOES weather satellite system.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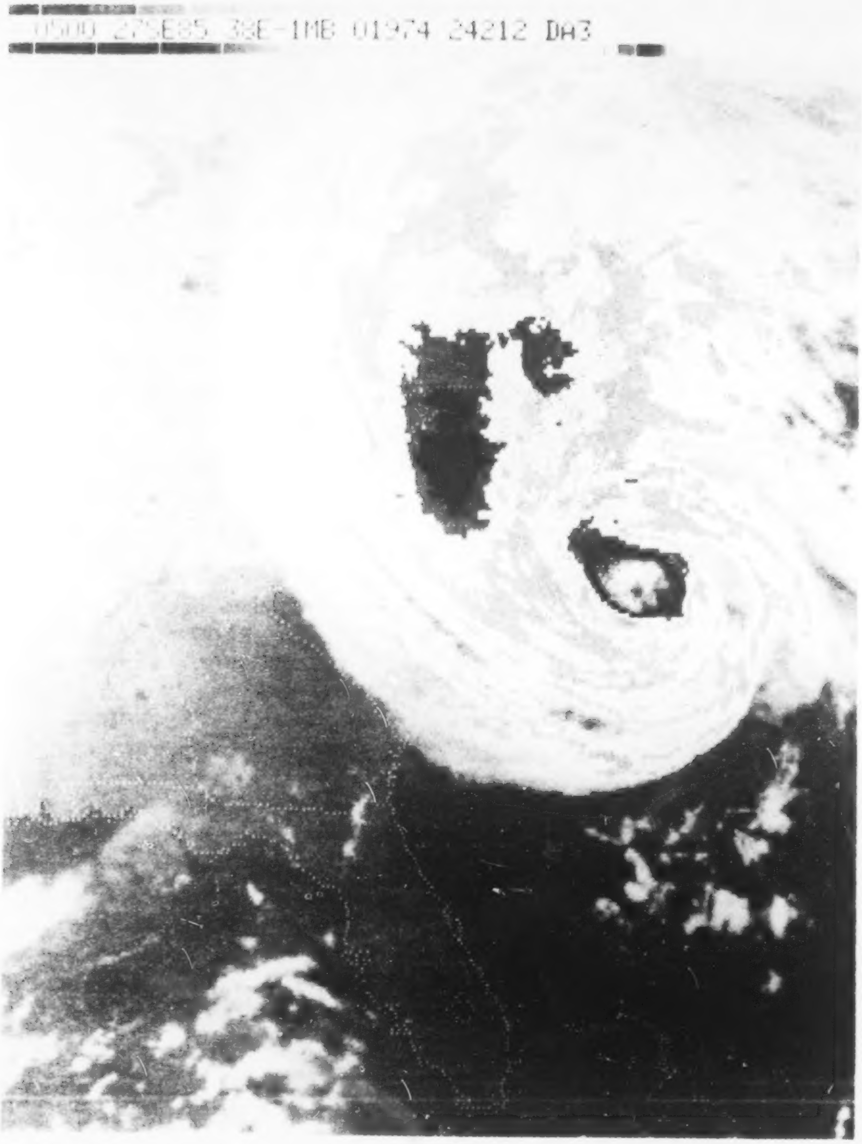
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Mr. LEWIS. Thank you, Mr. Koffler. Mr. Stang.

Mr. STANG. Thank you, Mr. Chairman. I am very happy to have the opportunity to be here today and appear before the Committee in Florida.

What I am going to try and do for you is present what the new weather data capabilities are of the GOES NEXT or the GOES-I through M weather satellite systems and compare the characteristics of these systems in a very brief manner, to give you a better idea of what to expect in the future when we do launch the first of the new series. And to help me there, we have brought two models, one of the current series of satellites. We manufactured at Ford Aerospace the first five of the original GOES that were launched beginning in 1974. And that is shown on the right, my right. The new series, the three-axis stabilized that Mr. Koffler referred to, which is currently under design and manufacture is shown on the left.

Now unfortunately the scale models that are there are not to the same scale. The new GOES satellite is roughly about three times the size of the spin-stabilized satellite that is shown on the right, and that is true from a mast point of view and also from a power point of view and the distance between the ends of the solar panels and the solar sail is about 96 feet in the new generation satellite.

The current series and the GOES-7 that is flying now is the spin-stabilized version and one of the characteristics of spin-stabilized stations is that it only has the ability of looking at the earth 5 percent of the time. The other 95 percent of the time it is spinning and looking at something other than the earth. It spins at a rate of 100 revolutions per minute, and it has but a single instrument on board the satellite.

Now to give you just a little bit more background quickly, I have brought some charts which I would like to share with you. Is that permissible.

Mr. LEWIS. Yes, sir.

I think maybe for everyone to see it, we could move the easel up to the side and then I believe the people in the audience could also see the charts as well.

[The easel was moved.]

Mr. STANG. Shown on this first chart is something which we talked about quite a bit already this afternoon. It shows the relative coverage to the east and to the west of a two satellite operational system, and what the current GOES-7 is capable of seeing as a single system. That is the inner circle that you see here.

So going to the east and the genesis of the hurricanes, we see the differential between here and here as to what a one-satellite system sees versus a two-satellite system. And then going to Dr. Sheets comments with regard to Alaska and Hawaii for the winter type conditions of bringing the weather in from the west, you can see what the relative position is. It is a chart that really enables you to take a look at what is available from a one-satellite system.

What I have tried to do here, and I am not going to read this, it is part of the statement, is to show you what are the improvements that one can expect from the new generation GOES I through M satellites that our company is manufacturing for NASA/Goddard Space Flight Center for use by NOAA. And I think the key items to bear in mind is the first one, where we have the ability for the first time on orbit, to have simultaneous imaging or picture-taking and atmospheric sounding. Now what is atmospheric sounding? That is being able to measure from a satellite the temperature profile and the water vapor profile that exists in the atmosphere and serves a primary purpose as an input into the numerical models that Dr. Sheets had in his testimony for long-range prediction purposes.

The other items I think—I am having a problem here——

[Laughter.] [Charts fell down]

Mr. STANG. This is not the normal Ford quality. Now this is not intended to be a complicated chart, but it is to give you a feel for the improved data that one will be able to get from the next generation of weather satellites to those parameters that are so important for severe storms and hurricanes. It is the ability to be able to measure the cloud height and the position of those clouds with time in order to be able to determine the movement of the severe storms. This is what the current GOES-7 system provides compared to what is expected out of the next generation, GOES I through M. Another key factor is the increase in the number of sensing channels, which means that we are able to see clouds, we are able to see weather in different parts of the spectrum. It is kind of like putting on five different pairs of sunglasses versus only having two sunglasses available. You are going to see moisture coming in at different levels, clouds moving differently and especially at night when the GOES satellites still operate and those weather channels that are in infrared and you can still see at night without having the sunlight. That will be a significant improvement.

The atmospheric sounding, remember is now going to be simultaneous and continuous. The number of channels will increase which will provide again increased sensitivity, increased ability to know where you are pointing so that you are getting accurate profiles of what is happening in the atmosphere. That data will be available from GOES I through M.

The ability to scan with the three-axis system that is constantly looking at earth as opposed to only looking at it 5 percent of the time is shown here. And I took two things that you can do with this satellite. You can program from the ground, take a complete earth picture from the north pole to the south pole, get all of South America all the way to the east, all the way to the west once every 25 minutes. While you are doing that if you do have some severe storms, you can program your scan, interrupt it as it is doing it, and take a small area scan and get your visible and infrared picture in about 20 to 30 to 40 seconds. And concurrently be doing atmospheric sounding of what is occurring in that storm area.

So I look at this as a storm area that is probably a series of squall lines producing heavy thunderstorms and heavy winds. You can continue to go back and do the whole scan of the earth, interrupt it again and come down to a hurricane genesis area, do a larger scan, and again get your pictures out of it and your soundings out of it that will serve as a data input to the Hurricane Center. We can do that concurrently with soundings and images and do this, this and still do the whole earth scan in roughly about

25-26 minutes. And I think that is going to be a significant improvement over the existing system.

With the platform that the three-axis stabilized spacecraft offers, there are a number of people within NASA and within NOAA that are developing the next generation of instruments to improve the observing of hurricanes and severe weather for improvements to the forecasting parts of the National Weather Service.

I have shown three here that are logical candidates beyond probably the year 2000 that can be added to the existing platform that is currently under development to improve the ability for measuring various parameters, forecasting techniques for future storm activities.

Thank you.

[The prepared statement of Mr. Stang follows:]

STATEMENT OF FRED W. STANG
DIRECTOR, BUSINESS DEVELOPMENT AND PLANNING OFFICE
FORD AEROSPACE CORPORATION
SPACE SYSTEMS DIVISION
BEFORE THE HOUSE SCIENCE, SPACE AND TECHNOLOGY COMMITTEE
SUBCOMMITTEE ON NATURAL RESOURCES, AGRICULTURE RESEARCH AND ENVIRONMENT
APRIL 7, 1989

Mr. Chairman and members of the Committee, I am pleased to appear before you today presenting the environmental data gathering capabilities of the new GOES I-M Weather Satellite System.

As you can see, I have brought with me models of the original Ford Aerospace GOES design - the first in the series of five we manufactured - and the next generation GOES I-M that we are currently developing under contract with the NASA/Goodard Space Flight Center. The Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) provides funding for both procuring and operating the spacecraft.

The current GOES spacecraft is spin-stabilized at a rate of 100 revolutions per minute. This technique has been the design concept for all of the GOES satellites launched to date. This results in the spacecraft instruments looking at the earth only 5% of the time. The GOES I-M spacecraft does not spin - it is stabilized in three axes permitting earth viewing from geostationary orbit at all times.

For your background purposes, Chart #1 shows the effective earth coverage for weather pictures and atmospheric temperature and moisture profiling. The normal NOAA operational GOES system has two satellites on-orbit: one at 70° west longitude and the second at 135° west longitude, as shown. As you know, the western-most GOES satellite failed in January 1989. To compensate, the eastern satellite has been moved westward and the effective coverage of this single GOES system is also shown.

Though Ford Aerospace developed and built the first five geostationary weather satellites for NASA/NOAA, we did not manufacture the current operational satellites. The system requirements and operation of the current satellite have many similarities with the original system. Chart #2 provides a summary of the significant improvements that the GOES I-M weather satellites will provide over the current series. Of particular significance is the ability to provide simultaneously and independently both weather pictures and atmospheric sounding. This can only be accomplished with two separate instruments. The current GOES has a single instrument that can provide either weather pictures or atmospheric sounding, but not both concurrently. Also, additional spectral sensing channels to aid in the detection and tracking of storms are provided in the GOES I-M instruments, about which I will provide details later in this hearing. Also, please note on Chart #2 the programmable real-time small area scanning capabilities that the 3-axis stabilized spacecraft can provide for severe storm monitoring and tracking without interference with the normal operational requirements of the National Weather Service. The GOES I-M will also initiate the operational geostationary search and rescue capability (SARSAT).

Chart #4 provides a tabular summary of the capabilities of the current GOES and the GOES I-M for the primary instruments of weather pictures (images) and atmospheric sounding. The new GOES provides both visible and infrared pictures in five channels, compared with the existing two channels. This enhances the capability of determining wind speed and direction, cloud heights and the movement within the atmosphere of significant amounts of moisture which "fuel" the severe storm systems. Also, because of the satellite's advanced image navigation and registration system, accurate and repeatable instrument pointing is achieved.

Atmospheric sounding -- determination of temperature and moisture with altitude will be available continuously from GOES I-M. The number of discrete channels is increased from 12 to 19, permitting significantly increased measurements. The weather sounder data are used as primary inputs to the NOAA numerical prediction models for forecasting. Because of the increased number of channels, sensitivity, and earth location and pointing capabilities, improved data will be available for the forecasting models.

Chart #3 is a specific example of the advanced weather sensing capabilities of the new system. In normal operation a full scan of the earth from the North Pole to the South Pole is accomplished in 25 minutes. When severe weather events are forming and/or in process (such as hurricanes, thunderstorms and tornadoes), the full earth scan is programmed to interrupt and view smaller area scans and then return to complete the full scan. As an example, I have shown on Chart #3 a small area scan, programmed to look at severe squall lines approaching Florida from the Gulf, which can be accomplished in 40 seconds. I have also shown a larger area scan to the south and east of Florida, which could be looking at a hurricane. Both can be accomplished in less than three minutes. Similar capabilities exist with the atmospheric sounder, which is programmable to look at any particular area of interest within these severe storm conditions. Also, please note that the system capabilities of the next generation GOES permit constant small area scans of severe weather when requested by the meteorologists. When you combine the increased resolution, sensitivity, and high accuracy earth location with immediately available pictures and sounding, the opportunities for improved severe storm tracking, detection, and forecasting are enhanced.

The government and Ford Aerospace have carefully planned the modular design of the spacecraft platform for future applications. The result is a platform that is highly stable with a state-of-the-art attitude control system for image navigation, precise earth pointing and geographic location repeatability from image-to-image or sounding-to-sounding. Therefore, the spacecraft platform will be able to accommodate new and improved instruments well into the 21st century. There have been a number of proposed new instruments for future GOES systems, and Chart #5 shows three under consideration. If these sensors are deployed, they will improve data gathering from weather satellites.

Thank you Mr. Chairman, I would be happy to discuss any questions which you or other members of the Committee might have regarding the improved weather sensing capability of the GOES I-M weather satellite system.

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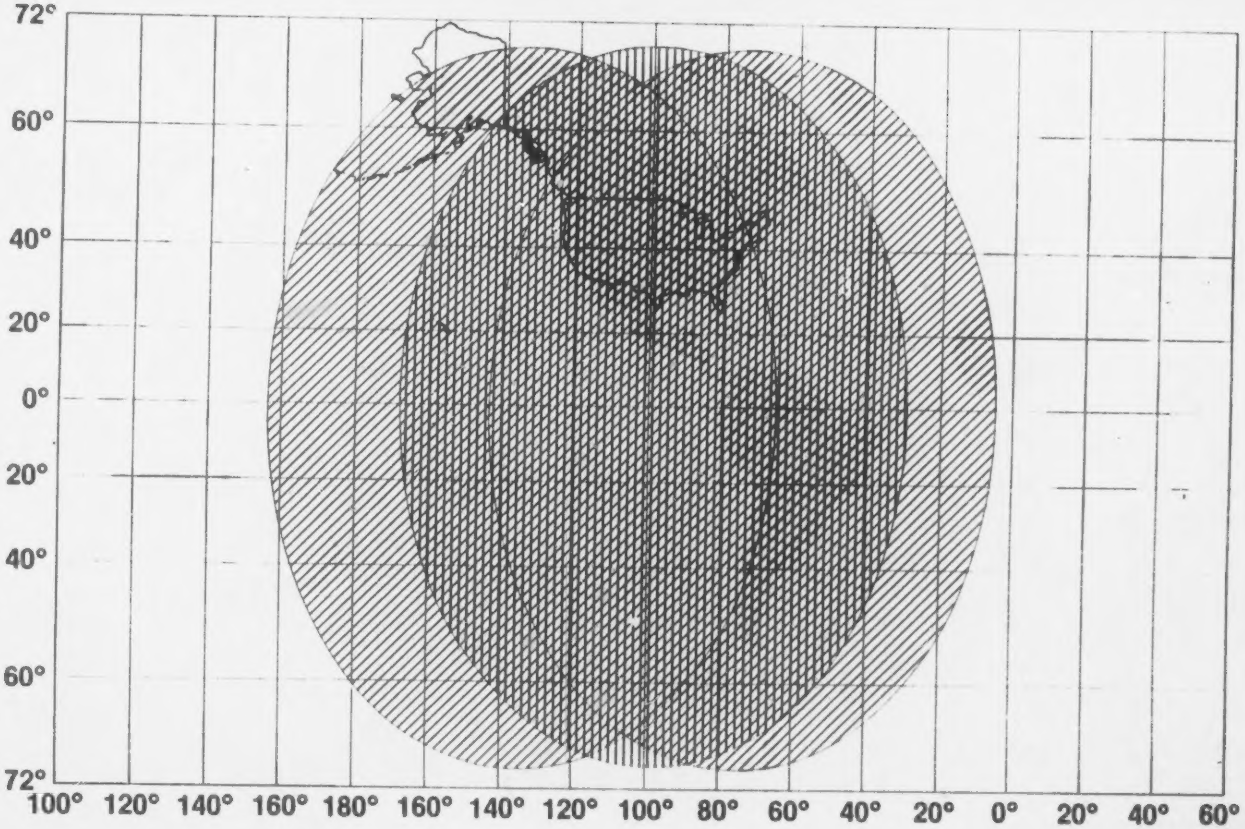
72°
60°
40°
20°
0°
20°
40°
60°
72°
100°
120°
140°
160°
180°
160°
140°
120°
100°
80°
60°
40°
20°
0°
20°
40°
60°

Ford Aerospace / Space Systems Division

Chart 1

GOES I-M: Improvements to the Satellite Weather Observing System

- Simultaneous and independent imaging and atmospheric sounding
- Programmable real-time severe storm monitoring and tracking
- New instruments: Increased resolution, sensitivity, and earth location accuracy
- Continuous WEFAX data distribution capability
- Data collection from remote ground based sensor systems maintained
- Inaugurates Operational Geostationary Search and Rescue (SARSAT)
- Advanced Space Environmental Monitoring System (SEM)
- Spacecraft platform ready for the next generation of instruments

Imager Scan Field

- ◆ Maximum Frame Field 19.2° E-W BY 19° N-S Maximum Star Field 23° E-W by 21° N-S
- ◆ Full Earth Limb Scan in 25.0 Minutes
- ◆ Earth Scan 60° N-S by 60° E-W in 22.0 Minutes
- ◆ Area Scan 3000 km by 3000 km in 3.0 Minutes (5 Min Required)
- ◆ Small Area Scan 1000 km by 1000 km in 40 Seconds

Sounder Scan Field

- ◆ Maximum Frame Field 23° E-W by 21° N-S (Star Sense Only)
- ◆ Full Earth Sounding 60° N-S by 60° E-W in 464 Minutes
- ◆ Area Sounding 3000 km by 3000 km in 42 Minutes
- ◆ Small Area Sounding 1000 km by 1000 km in 5.0 Minutes

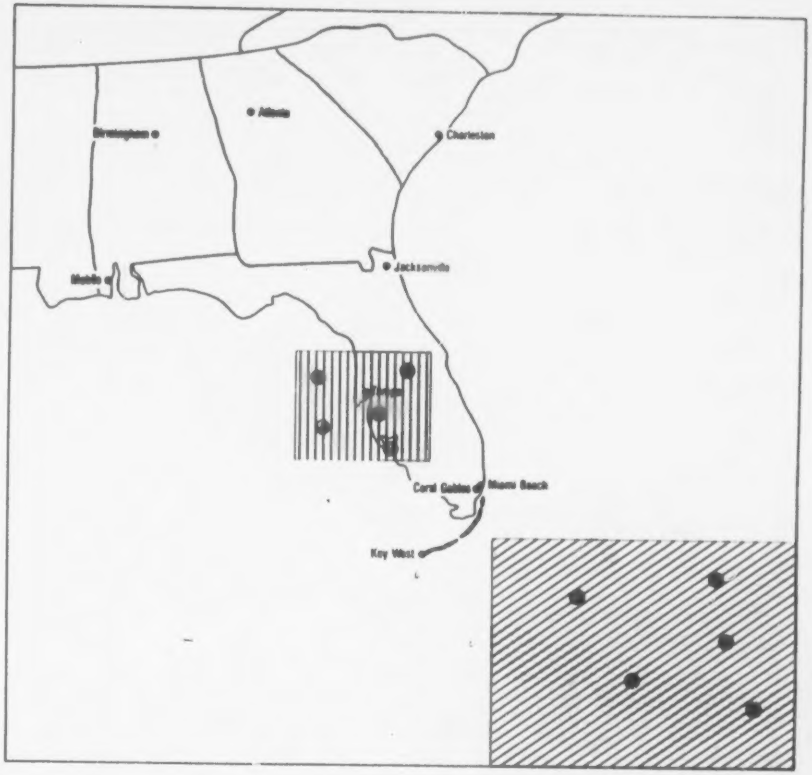
Birmingham
Atlanta
Charleston
Mobile
Jacksonville
Coral Gables
Miami Beach
Key West

Chart 3

Performance Comparison

Parameter	Current GOES	New GOES I-M
Weather Images		
Number of Channels	2 Channels	5 Channels
Derived Wind Speed/Direction	5-10 M/s	1.5-7 M/s
Cloud Height (Accuracy)	2500 M ± 500 M	1500-2000 M ± 400-500 M
Severe Storm Tracking		
Earth Location	Accuracy ± 10 Km	Accuracy ± 2-6 Km
Availability	Part Time Only	Always Available - Fast Scan
Atmospheric Sounding		
Number of Channels	12 Channels	19 Channels
Temperature Profile (Accuracy)	$>2.5°C$	$<2.0°C$
Moisture Profile (Accuracy)	30% Relative Humidity	20 - 25% Relative Humidity
Spatial Resolution	30 - 90 Km	10 - 50 Km
Availability	Part Time Only	Always Available - Fast Scan

Future GOES Instrument System

- ◆ **Lighting Mapper Sensor**
  Will detect and locate lightning for warning and avoidance; Improves severe weather forecasting
- ◆ **X-Ray Imager**
  Will image the solar corona; Monitors high altitude safety and communication interruptions
- ◆ **Microwave Radiometers**
  Will improve atmospheric sounding measurements and provide ''All weather'' capability; Improves severe storm detection and warning

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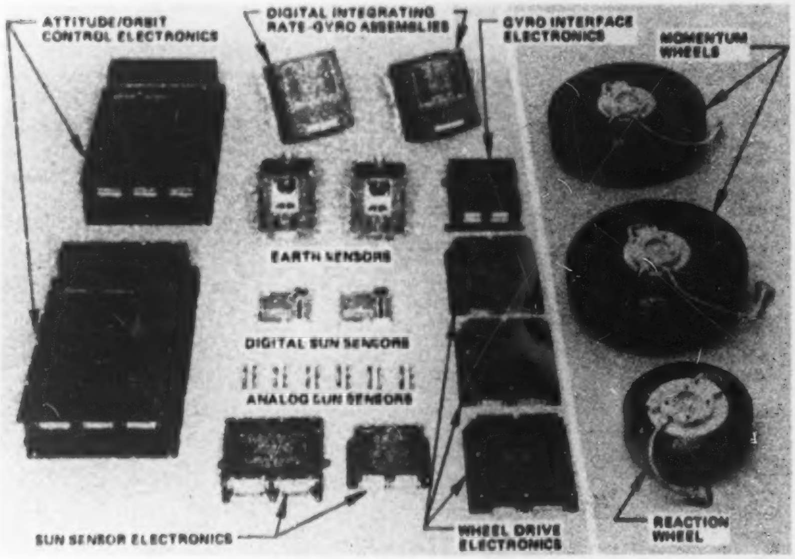
Chart 5

GOES IJK/LM

FLIGHT-PROVEN ATTITUDE/ORBIT CONTROL SUBSYSTEM


ATTITUDE/ORBIT CONTROL ELECTRONICS
DIGITAL INTEGRATING RATE-GYRO ASSEMBLIES
GYRO INTERFACE ELECTRONICS
MOMENTUM WHEELS
EARTH SENSORS
DIGITAL SUN SENSORS
ANALOG SUN SENSORS
SUN SENSOR ELECTRONICS
WHEEL DRIVE ELECTRONICS
REACTION WHEEL

THE ATTITUDE/ORBIT CONTROL SUBSYSTEM (AOCS) PROVIDES:

- Three-axis stabilized control of satellite attitude in geostationary transfer orbit to support apogee motor firing.
- On-station, three-axis stabilized and momentum-biased control concept to maintain stability for Imager/Sounder observations and for antenna pointing accuracy.
- Image Motion Compensation (IMC) and Mirror Motion Compensation (MMC) to the Imager/Sounder mirror control servos to compensate for satellite orbit inclination, satellite thermal distortion, satellite attitude, and mirror scanning disturbances.
- Magnetic Torquer Coils

ATTITUDE/ORBIT CONTROL SUBSYSTEM COMPONENT HERITAGE

Equipment Description	Manufacturer	Heritage
Coarse Analog Sun Sensor Assembly	Adcole	INTELSAT-V, INSAT, ARABSAT
Digital Integrating Rate Assembly	Northrop	INSAT, ARABSAT
Earth Sensor	Lockheed	INTELSAT-V, INSAT, ARABSAT
Momentum Wheel Assembly	Teldix	INTELSAT-V, TV-SAT, ETS-V
Reaction Wheel Assembly	Teldix	INTELSAT-V, TV-SAT, ETS-V
Digital Sun Sensor	Adcole	INSAT, ARABSAT
Attitude/Orbit Control Electronics	Ford Aerospace	INSAT, ARABSAT

GOES IJK/LM ATTITUDE/ORBIT CONTROL SUBSYSTEM FEATURES

- Flight-proven subsystem components.
- Subsystem is fail-safe and subsystem components are redundant and cross-strapped.
- Patented Image Motion Compensation and Mirror Motion Compensation scheme allows completely independent operation of Imager and Sounder.
- Simple three-axis momentum biased control requires no Yaw sensing. Yaw errors are bounded by gyroscopic stiffness and controlled in the Roll channel via quarter-orbit Roll/Yaw kinematic coupling.
- The use of multimode and selectable control laws combined with the benign failure modes of a momentum biased configuration yields a highly reliable and operationally versatile design.
- Processor-based Attitude/Orbit Control Electronics (AOCE) allows on-orbit reprogramming.

GOES IJK/LM

IMPROVED METEOROLOGICAL DATA PRODUCTS

- Initial product menu benefits from improved GOES sensors and operating capabilities:
    - Increase from 2 to 5 Imager channels.
    - Increase from 12 to 19 Sounder channels.
    - Almost doubled imager infrared (IR) resolution.
    - Greater frequency of operational observations.
    - Increased Earth location accuracy.

- Cloud imagery available in mapped format as well as familiar GOES projection sectors:
    - CONUS, Hawaii, and Puerto Rico mapped to Mercator projection.
    - Polar stereographic mapped product for Alaska.
    - Mapped products available for each Imager channel.
    - Two composite images produced: visible-IR and IR-water vapor.
    - Winds from cloud motions, surface temperature, low level moisture, cloud top heights

- Separate Sounder pioneers continuous availability of geostationary sounding products for mesoscale analysis and forecasting:
    - Higher accuracy due to increased sounding channels.
    - Vertical temperature and moisture profiles.
    - Increased spatial resolution of profiles from 30 km to 10 km.
    - Layer mean temperature and moisture.
    - Total precipitable water and lifted index - both available as images.

GOES IJK/LM METEOROLOGICAL DATA PRODUCTS

Data Product	System Accuracy	Horizontal Resolution	Vertical Resolution	Earth Coverage	Observation Frequency	Mission Sensor
CLOUD IMAGERY:	Location					
GOES Projection	±4 km	Vis 1 km IR 4-8 km	–	3/4 - full disk 3000 x 3000 km 1000 x 1000 km	15-30 min 5 min 40 sec	Imager Channels 3 long wave* 1 short wave* 1 visible
Mercator Projection						
Polar Stereo Projection	±12 km	Vis 6 km IR 10-18 km	–	Alaska	15 - 30 min	
Composite Images	±2 km	Vis 1 km IR 4-8 km	–	Continental US	15 - 30 min	Imager Vis/11.5 μm IR 11.5/6.7 μm IR
CLOUD HEIGHTS:	±10 km	8 km	±50 mb	Continental US	60 min	Imager
SOUNDINGS:	vs. Radiosondes					
Vertical Temperature Profile	2.5°K	30 - 50 km	3 km	Continental US/ adjacent Pacific & Atlantic Oceans	60 min- 6 hr	Sounder 7 long wave* 5 medium wave* 6 short wave* 1 visible
Vertical Moisture Profile	±30%	30 - 50 km	3 km			
Layer Mean Temperature	2.5°K	30 - 50 km	15 levels			
Layer Precip - H_2O	±20%	30 - 50 km	15 levels			
DERIVED IMAGES:						
Total Precipitable Water	±20%	8 km	–	Continental US	60 min	Sounder
Lifted Index	±2	8 km	–	Continental US	60 min	Sounder
PRECIPITATION ESTIMATES:	±30% of event	4 km	–	Continental US	30 min	Imager
WINDS:						
Cloud Drift Winds	Low level 2 - 5 mps High level 5 - 10 mps	150 - 200 km	±50 mb	50° N - 50° S	6 hrs	Imager Vis 11.5 μm 6.7 μm
Thermal Gradient Winds	10 mps	150 - 200 km	10 levels	50° N - 50° S	6 hrs	Sounder
Deep Layer Mean Winds	5 mps	150 - 200 km	1 level	50° N - 50° S	12 hrs	Imager/Sounder

*Thermal IR

GOES IJK/LM

THE FORD AEROSPACE IMAGE NAVIGATION AND REGISTRATION (INR) METHODOLOGY MEETS STRINGENT PERFORMANCE REQUIREMENTS

	Imager Max. Orbital Inclination		Sounder Max. Orbital Inclination	
	0.1°	0.5° (Goal)	0.1°	0.5° (Goal)
• Earth Location (km), 3σ				
– At nadir	±4	±4	±10	±10
– At 60° central angle	±11.76	±11.76	±29.4	±29.4
• Registration (μrad), 3σ				
– Within same image	42	48	–	–
– Within 90-minute interval	84	96	–	–
– Within 120-minute interval	–	–	84	96
– 24 hours interrupted by up to three 10-minute housekeeping periods	168	190	280	322

- Navigation and Registration accuracy requirements (3 sigma) are achieved for orbital inclination values:
  - 0.1°: the maximum orbital inclination during nominal 5-year lifetime.
    - Orbital inclination maintained by thruster firing in North direction once every 2 months.
    - North-South stationkeeping - consumes majority of on-station propellant.
  - 0.5°: the maximum orbital inclination during nominal 5-year lifetime (goal).
    - Adds one year to nominal 5-year lifetime.
    - Orbital inclination maintained by thruster firing in North direction once every year.
- Navigation (Earth Location) Accuracy
  - Earth location accuracy of a pixel specified at nadir (subsatellite point) and at 60° Earth central angle from nadir.
  - Values at 60° central angle are 2.94 times nadir values due to curvature of the Earth.

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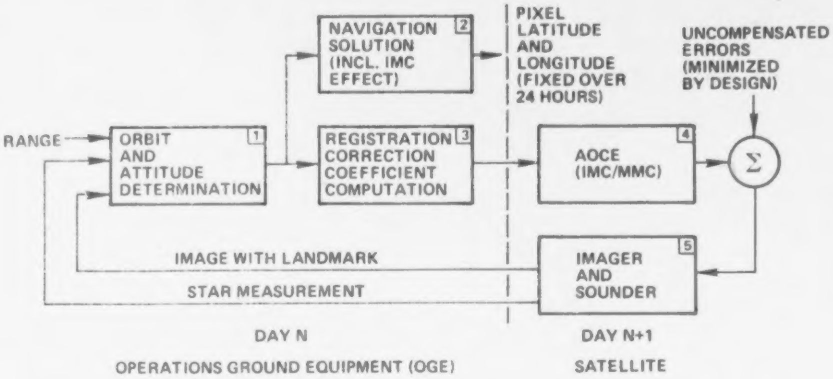
- Registration Accuracy
  - 90-minute interval approximately equals time for four consecutive full Earth images.
  - Requirement driven by wind velocity calculation accuracy.
  - Requirements for 24 hours driven by need to superimpose ground radar data on the spacecraft imagery data.
  - Up to three 10-minute intervals allocated during any 24-hour period for housekeeping functions, e.g., thruster firings required for momentum wheel unloading, small orbit changes, trim tab positioning adjustment, X-ray sensor calibration.

GOES IJK/LM

CLOSED-LOOP IMAGE NAVIGATION AND REGISTRATION (INR) SYSTEM


NAVIGATION SOLUTION (INCL. IMC EFFECT) 2
PIXEL LATITUDE AND LONGITUDE (FIXED OVER 24 HOURS)
UNCOMPENSATED ERRORS (MINIMIZED BY DESIGN)
RANGE
ORBIT AND ATTITUDE DETERMINATION 1
REGISTRATION CORRECTION COEFFICIENT COMPUTATION 3
AOCE (IMC/MMC) 4
Σ
IMAGE WITH LANDMARK
STAR MEASUREMENT
IMAGER AND SOUNDER 5
DAY N
DAY N+1
OPERATIONS GROUND EQUIPMENT (OGE)
SATELLITE

THE FORD AEROSPACE APPROACH TO MEETING INR REQUIREMENTS REPRESENTS A TECHNOLOGICAL ADVANCEMENT

- Range data (altitude) combined with star and landmark observation data (angles) used in orbit and attitude determination process (block 1).
- Star and landmark data are taken through the Imager (and Sounder) itself (block 5); thus, *all long-term effects* are "zeroed out" (i.e., the effect is the same for each pixel as it is for the star and the landmark).
- Once long-term effects are modeled by Operations Ground Equipment (OGE, block 3), the mirrors are biased in azimuth and elevation to compensate for those effects (block 4).
- Thus, remaining errors in *Earth location* (block 2) and *registration* of each pixel (block 5) are due primarily to the following uncompensated errors that are minimized by design:
  - Satellite response to Earth sensor noise
  - Imager/Sounder servo errors
  - Solar array stepping effect
  - Momentum wheel imbalance effect
  - IMC/MMC implementation errors
  - Magnetic field variation effect on satellite yaw

- The errors compensated on-board the GOES IJK/LM satellite are:

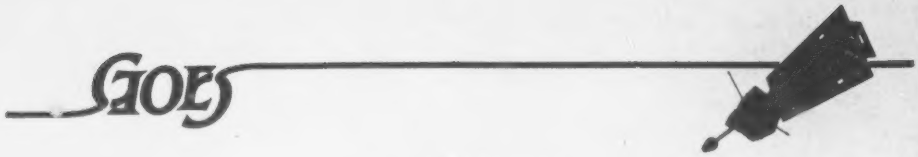
  a. Mirror Motion Compensation (MMC) for satellite rigid body disturbances caused by mirror motion:
     - Normal scan motion
     - Retrace motions
     - Blackbody calibration
     - Star scan motions

  b. Image Motion Compensation (IMC) for disturbances from:
     - Satellite thermal distortions
     - Instrument thermal distortions
     - Earth sensor thermal distortions
     - Satellite yaw
     - Orbital deviations

  MMC and IMC corrections added in Attitude and Orbit Control Electronics (AOCE) before output to Imager and Sounder.

Designing to Difficult Performance Requirements is Avoided

- IMC design corrects for known mechnical and thermal distortions which are determined by star measurement; allows relaxation of optical alignment requirements.
- Without INR system, detector alignment to scan axis requires 5 μradian accuracy (extemely difficult design problem); with INR requirements can be relaxed to 125 μradian.



GOES IJK/LM

A COST-EFFECTIVE PLATFORM FOR RESEARCH AND DEVELOPMENT OF SENSORS

Sensor	Physical Climate Cycle	Hydrologic Cycle	Biogeochemical Cycle
Microwave Sounder	X	X	
High Resolution Imager	X	X	X
Lightning Mapper	X	X	
Ozone Mapper	X	X	X
Michelson Sounder	X	X	X
Fabry-Perot Sounder	X	X	X
Active Cavity Radiometer	X		
Climate Radiation Radiometer	X		
Solar Disk Sextant	X		
X-Ray Imager	X		
Laser Ranger	X		
Flight Model Discharge System	X	X	

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GOES-BASED SENSOR R&D SUPPORTS MISSION TO PLANET EARTH

Physical Climate Cycle

- Atmospheric carbon, sulfur, nitrogen, halogen
- Sea surface topography, current, waveheight, wind, temperature
- Sea ice boundaries, ice temperature
- Earth radiation budget
- Cloud top height, temperature albedo, thickness
- Atmospheric wind, ozone, temperature, humidity, pressure
- Solar radiation
- Particle energy
- Plasma
- Electric field
- Episodic events (e.g., volcano, earthquake)

Hydrologic Cycle

- Soil moisture
- Surface temperature
- Vegetation type and cover
- Albedo
- Precipitation
- Snow cover area, depth
- Landslide
- Evaporation
- Topography
- Air temperature, humidity
- Soil type condition
- Water coverage

Biogeochemical Cycle

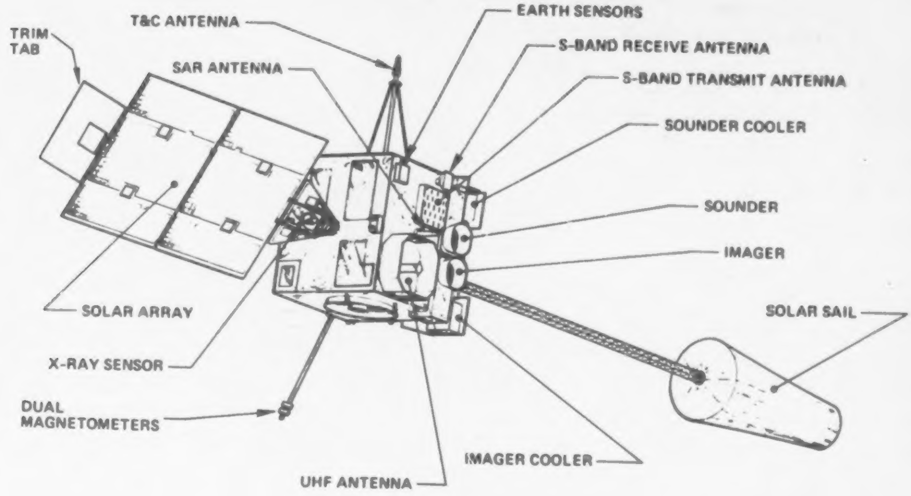
- CO_2, CO, N_2O, CH_4, H_2S, NH_3
- Ocean color
- Ocean eddies
- Wetland area
- Leaf area and chemistry

Ford **Ford Aerospace**, Space Systems Division, Palo Alto, CA 94303-4697, Phone: 415/852-6989

GOES

GOES IJK/LM

THE GOES IJK/LM SATELLITES: PRIME ELEMENTS OF WEATHER WATCH 1990


TRIM TAB
T&C ANTENNA
SAR ANTENNA
EARTH SENSORS
S-BAND RECEIVE ANTENNA
S-BAND TRANSMIT ANTENNA
SOUNDER COOLER
SOUNDER
IMAGER
SOLAR SAIL
SOLAR ARRAY
X-RAY SENSOR
DUAL MAGNETOMETERS
IMAGER COOLER
UHF ANTENNA

GOES IJK/LM SATELLITE ON-ORBIT CONFIGURATION

GOES IJK/LM is the new generation of meteorological satellites developed for NOAA's Geostationary Operational Environmental Satellite system. Designed and built by Ford Aerospace, these satellites capture the latest advances in sensor technology for meteorological observation and space environment monitoring. The GOES IJK/LM series will serve as one of the primary observation platforms in NOAA's Weather Watch of the 1990's.

Ford Aerospace

GOES IJK/LM SATELLITE

- Designed, Developed and Built by Ford Aerospace
  - Capitalizes on legacy of SMS, GOES 1, 2, 3, and INSAT-1
  - Three-axis body-stabilized platform permits onboard sensors to "stare" at the Earth
  - Design versatility allows expanded instrumentation
  - Easily accommodates future growth

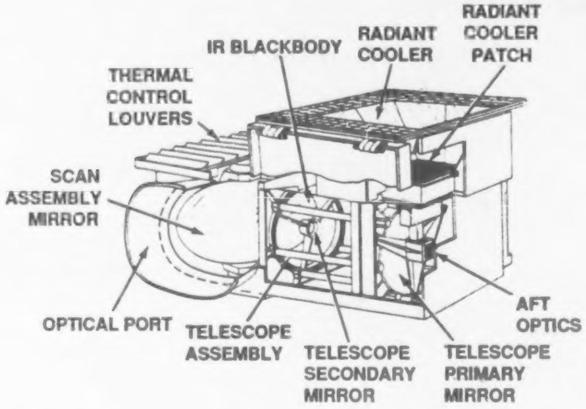
- Serves as Primary Observing System in NOAA's Weather Watch of the 1990's
  - GOES-I scheduled for launch in 1990 aboard ATLAS-1 (Atlas/Centaur)
  - On-orbit lifetime 5 to 7 years
  - Adaptable to Shuttle launch

- Continues Present Services with Improved Short-Term Forecasting of Dynamic Weather Events Over Local Areas
  - Provides higher quality data in less time
  - Features pinpoint Earth location accuracy

- Captures Advances in Technology
  - Flexibility of scan control permits small area coverage in addition to hemispheric and global scenes
  - Simultaneous and independent imaging and atmospheric sounding sensors supplied by ITT's Aerospace/Optical Division provide:
    - Improved short range forecasts and storm warnings
    - Improved cloud and water vapor measurements via three new imaging channels
    - Higher infrared resolution for improved weather images
  - Improved communications capability permits continuous Weather Facsimile (WEFAX) transmission
  - Improved space environment monitoring sensors provide better measurements of the electromagnetic environment near Earth
  - Continues the search and rescue (SAR) mission at geostationary orbit
    - Relays distress signals from aircraft or marine vessels

GOES IJK/LM

IMAGING SUBSYSTEM PROVIDES EARTH SCENE IMAGES OF THE WESTERN HEMISPHERE CONTINENTS AND OCEANS


RADIANT COOLER PATCH
IR BLACKBODY
RADIANT COOLER
THERMAL CONTROL LOUVERS
SCAN ASSEMBLY MIRROR
OPTICAL PORT
TELESCOPE ASSEMBLY
TELESCOPE SECONDARY MIRROR
TELESCOPE PRIMARY MIRROR
AFT OPTICS

FEATURES

- Earth surface scan from GEO orbit
- Five spectral bands - 0.7 to 12 microns
- High resolution:
  - 1 km visible
  - 4 km shortwave and longwave thermal infrared windows
  - 8 km moisture thermal infrared
- High precision temperature measurement

PRODUCTS

- Day-night imaging of land, water, and clouds
- Surface temperature
- Moisture imaging
- Cloud tracking to obtain winds
- Cloud height and amount
- Storm monitoring

DETAILED IMAGER FEATURES

- Data Rate: 2.6208 Mbps
- Simultaneous imaging from IR & visible channels
- Imaging Rate (frame selectable):

Full Earth images	25 minutes
3000 km x 3000 km	3.1 minutes
1000 km x 1000 km	40 seconds

- Combinations of these frames may be pre-programmed and repeated
- Pixel locations accurate to 2 km at nadir
- Independent and simultaneous operation with Sounder
- Mechanically independent and fully stable against other instrument and satellite motions
- Capable of interrupting long duration frames to permit priority (storm watch) observations with repeat-frame option
- Weight, Total: 260 pounds (118 kg)
- Power: 130 watts

SPECTRAL CHANNELS, DETECTORS, AND PURPOSE

Channel No.	Wavelength µm	Detector Type	Purpose
1	0.55 to 0.75	Silicon	Cloud and Surface Feature Mapping
2	3.80 to 4.00	In-Sb	Night Mapping
3	6.50 to 7.00	Hg-Cd-Te	Moisture Imaging
4	10.20 to 11.20	Hg-Cd-Te	Thermal Mapping
5	11.50 to 12.50	Hg-Cd-Te	Thermal and Moisture Mapping

SENSITIVITY

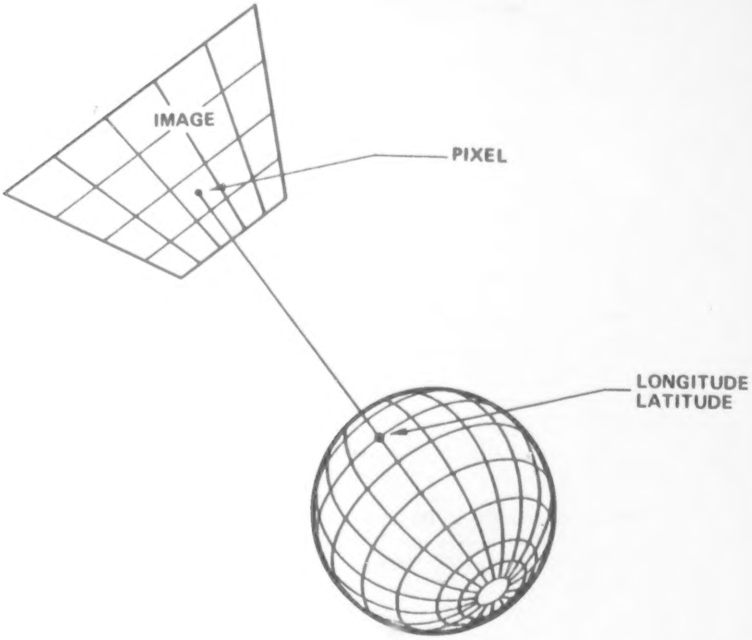
Channel No.	S/N or NEΔT	
	Spec	Plan
1	150:1	428:1 @ 100% Albedo
2	1.4K	0.09K @ 300K
3	1.0K	0.34K @ 230K
4	0.35K	0.12K @ 300K
5	0.35K	0.15K @ 300K

Ford Aerospace, Space Systems Division, Palo Alto, CA 94303-4697, Phone: 415/852-6989

GOES

GOES IJK/LM

IMAGE NAVIGATION AND REGISTRATION (INR) TECHNOLOGY BENEFITS THE USER COMMUNITY



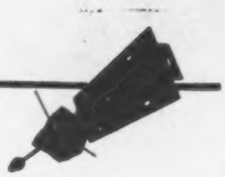
- Image *navigation* determines picture element (pixel) location within an image in terms of Earth longitude and latitude.
- Image *registration* compensates for orbit and attitude effects to assure each pixel points to the same geographic location independent of time. Image grid will be fixed, i.e., "fixed grid".
- Gridding of imagery data assigns locations of national and geographic boundaries to pixels.

Ford Aerospace

THE BENEFITS OF INR TO METEOROLOGY AND ATMOSPHERIC SCIENCES

- Image registration is performed on-board the satellite by continuously adjusting the gimbal angle of the Imager and Sounder mirrors.
    - Nullifies the orbit and attitude effects - image grid can be fixed.
    - No radiometric ground data processing or interpolation required to register imagery data - therefore, no loss of radiometric information.
    - No dynamic gridding on ground is required - "fixed grid".
- Image registration relative to a fixed grid:
    - Allows accurate superposition of ground radar data on the satellite imagery data.
    - Provides accurate wind velocity calculations from cloud motion relative to the fixed grid.
    - Eliminates the need for complex transformations to account for orbit and attitude motion.
- Registered and Earth-located pixels are transmitted to users in near real time (within a few seconds after a pixel is imaged).

GOES

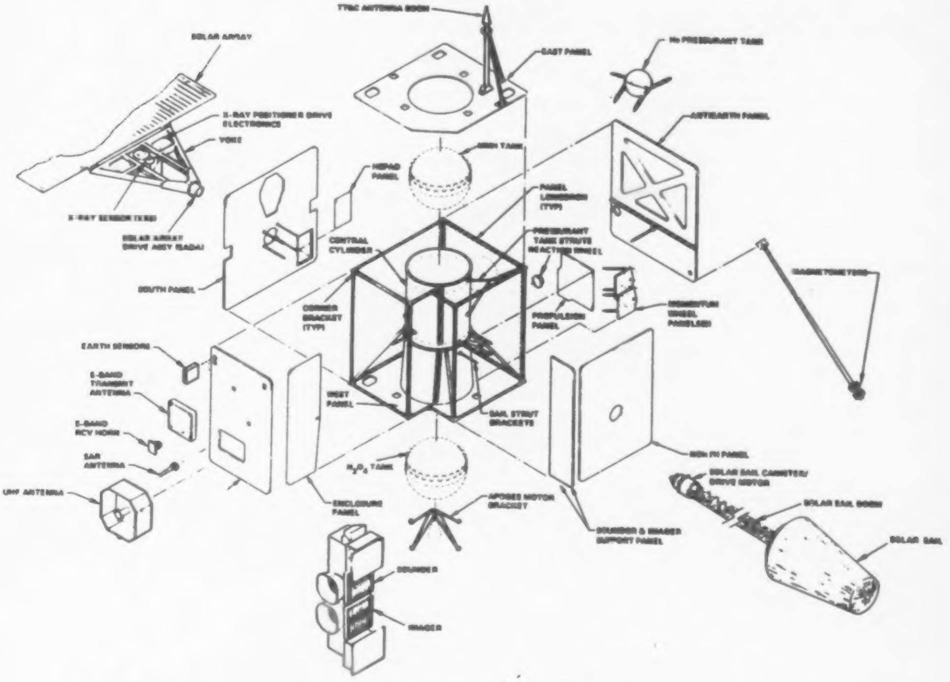


GOES IJK/LM

HIGH-PERFORMANCE EARTH OBSERVATIONAL PLATFORM FOR WEATHER WATCH 1990

GOES IJK/LM SATELLITE

(EXPLODED VIEW)


TT&C ANTENNA BOOM
SOLAR ARRAY
EAST PANEL
He PRESSURANT TANK
X-RAY POSITIONER DRIVE ELECTRONICS
YOKE
ANTIEARTH PANEL
MMH TANK
HEPAD PANEL
PANEL LONGERON (TYP)
X-RAY SENSOR (XRS)
SOLAR ARRAY DRIVE ASSY (SADA)
CENTRAL CYLINDER
PRESSURANT TANK STRUTS
REACTION WHEEL
MAGNETOMETERS
SOUTH PANEL
CORNER BRACKET (TYP)
PROPULSION PANEL
MOMENTUM WHEEL PANEL(S)
EARTH SENSORS
S-BAND TRANSMIT ANTENNA
WEST PANEL
SAIL STRUT BRACKETS
S-BAND RCV HORN
NORTH PANEL
SAR ANTENNA
N_2O_4 TANK
SOLAR SAIL CANISTER/DRIVE MOTOR
UHF ANTENNA
APOGEE MOTOR BRACKET
SOLAR SAIL BOOM
ENCLOSURE PANEL
SOUNDER & IMAGER SUPPORT PANEL
SOLAR SAIL
SOUNDER
IMAGER

GOES IJK/LM INSTRUMENT PAYLOADS

- Imager
- Sounder
- Space Environment Monitor (SEM)
  - Solar X-Ray Sensor
  - Energetic Particle Sensor
  - High-Energy Proton and Alpha-Particle Detector
  - Dual Magnetometers
- Sun Pointing Instrument Capability on Solar Array Yoke
  - XRS Baseline
  - XRI Plug-in Capability

MAIN BODY FEATURES

- 93 x 86 x 80 inches
- Antennas
  - S-band Receive
  - S-band Transmit
  - UHF
  - SAR
- Optical Solar Reflectors

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SATELLITE ON-ORBIT MODES

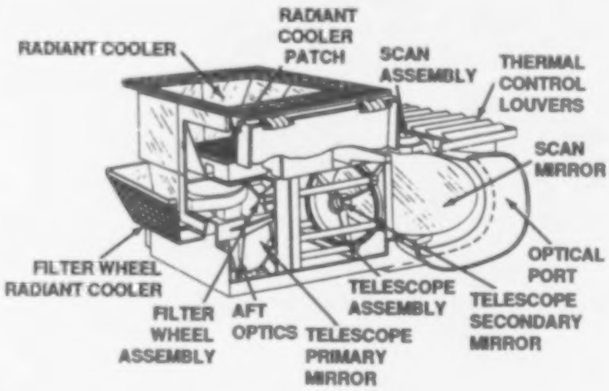
Mode	Imaging & Sounding	SEM	Comm	Control
Normal	On	On	On	Earth Pointing INR
Eclipse	Standby	XRS Off	SD PDR MDL WEFAX } Off	Earth Pointing
Stationkeeping	Standby	On	SD PDR MDL } Off	Earth Pointing
Standby/Storage	Standby	Off	As Required	

DEPLOYED APPENDAGES

- Sun Tracking Platform
  - Solar Array (each panel 93 x 105.5 inches)
  - Instrument Platform
  - Trim Tab (51 x 66 inches)
- Solar Sail 58 feet (17.7 meters)
- Dual Magnetometers on 118-inch (3-meter) Boom
- Deployed configuration 96 feet Tip-to-Tip

GOES IJK/LM

SOUNDING SUBSYSTEM PROVIDES EARTH ATMOSPHERE VERTICAL TEMPERATURE AND MOISTURE PROFILES


RADIANT COOLER
RADIANT COOLER PATCH
SCAN ASSEMBLY
THERMAL CONTROL LOUVERS
SCAN MIRROR
OPTICAL PORT
FILTER WHEEL RADIANT COOLER
TELESCOPE ASSEMBLY
TELESCOPE SECONDARY MIRROR
FILTER WHEEL ASSEMBLY
AFT OPTICS
TELESCOPE PRIMARY MIRROR

FEATURES

- Spot surface and atmospheric radiance measurement
- 19 spectral bands - 0.7 to 15 microns
- 10 km sample spacing (nadir) from GEO orbit with 8 km resolution
- Extremely sensitive measurement allows profiles at each spot

PRODUCTS

- Vertical temperature and moisture profiles
- Total precipitable water and precipitable water for three layers
- Cloud height
- Surface radiance and temperature

DETAILED SOUNDER FEATURES

- Data Rate: 40 Kbps
- Sounding Rate ± 50° of subpoint (frame selectable):

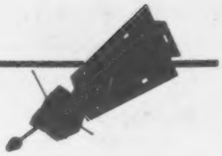
50°W - 50°E of subpoint,	
50°N to 0°N	3 hours
3000 km x 3000 km	41 minutes
Continental U.S.	35 minutes
1000 km x 1000 km	4.7 minutes

- Scene, each step 280 x 1120 μradians (10 km x 40 km)
- Combinations of these frames may be pre-programmed and repeated
- Sample locations accurate to 4 km at nadir
- Independent and simultaneous operation with Imager
- Mechanically independent and fully stable against other instrument and spacecraft motions
- Capable of interrupting long duration frames to permit priority (storm watch) observations with repeat-frame option
- Weight, Total: 278 pounds (126 kg)
- Power: 105 watts

SPECTRAL CHANNELS, DETECTORS, AND PURPOSE

Detector	Channel	Wavelength (μm)	Sensitivity (NEΔ N)*	Purpose
	1	14.70	0.66	Temperature
	2	14.37	0.58	Sounding
	3	14.06	0.54	
HgCdTe	4	13.64	0.45	
(Longwave)	5	13.37	0.44	
	6	12.66	0.25	
	7	12.02	0.16	Surface
	8	11.03	0.16	Temperature
	9	9.71	0.35	Total Ozone
HgCdTe	10	7.43	0.16	Water Vapor
(Midwave)	11	7.02	0.12	Sounding
	12	6.51	0.15	
	13	4.57	0.013	Temperature
	14	4.52	0.013	Sounding
InSb	15	4.45	0.013	
(Shortwave)	16	4.13	0.008	
	17	3.98	0.0082	Surface
	18	3.74	0.0036	Temperature
Silicon (Visible)	19	0.696	0.10%A	Cloud

* MW–M^{-2}–SR^{-1}–CM



GOES IJK/LM

SATELLITE GROWTH FLEXIBILITY ACCOMMODATES ADVANCED OPERATIONAL SENSORS

Microwave Sensor
- Temperature-Humidity Profile
- Precipitation
- Wind Field
- Sea Ice
- Surface Temperature

Lightning Mapper
- Severe Storm Detection
- Lightning Event Distribution

Ozone Mapper
- Temporal Variation in Ozone Concentration
- Definition of Atmospheric Circulation Features
- Tropopause Height

Improved Sounder
- Higher Vertical Resolution
- Improved Temperature Accuracy
- Improved Sensitivity
- More Channel Selection

Improved Imager
- Land and Ocean Objectives
- Higher Spatial Resolution
- More Channel Selection

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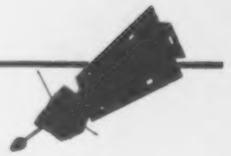
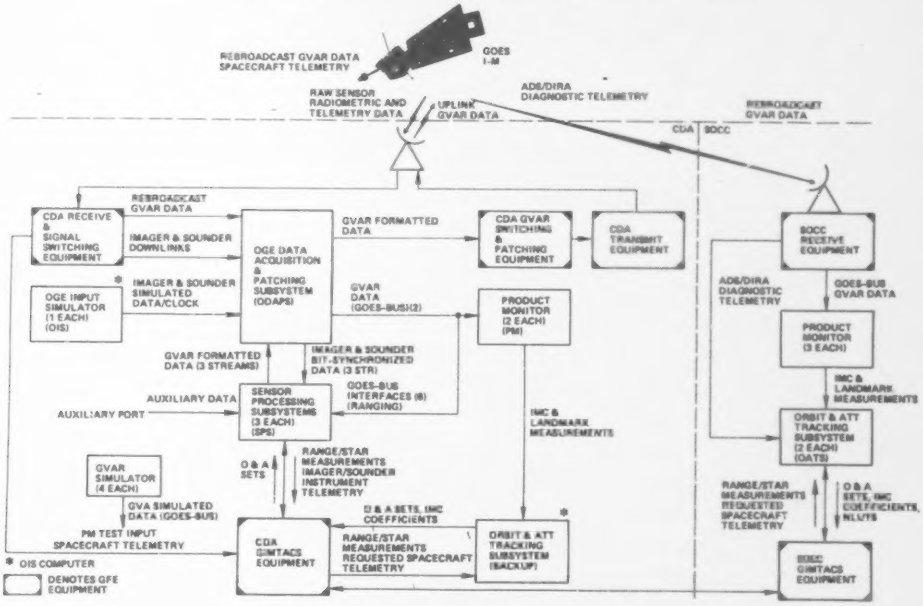


GOES IJK/LM

NEW OPERATIONS GROUND EQUIPMENT (OGE) PROVIDES IMPROVED DATA PROCESSING CAPABILITIES


REBROADCAST GVAR DATA
SPACECRAFT TELEMETRY
GOES I-M
RAW SENSOR RADIOMETRIC AND TELEMETRY DATA
UPLINK GVAR DATA
ADS/DIRA DIAGNOSTIC TELEMETRY
REBROADCAST GVAR DATA
CDA
SOCC
REBROADCAST GVAR DATA
CDA RECEIVE & SIGNAL SWITCHING EQUIPMENT
IMAGER & SOUNDER DOWNLINKS
OGE DATA ACQUISITION & PATCHING SUBSYSTEM (ODAPS)
GVAR FORMATTED DATA
CDA GVAR SWITCHING & PATCHING EQUIPMENT
CDA TRANSMIT EQUIPMENT
SOCC RECEIVE EQUIPMENT
OGE INPUT SIMULATOR (1 EACH) (OIS)
IMAGER & SOUNDER SIMULATED DATA/CLOCK
GVAR DATA (GOES-BUS)(2)
PRODUCT MONITOR (2 EACH) (PM)
ADS/DIRA DIAGNOSTIC TELEMETRY
GOES-BUS GVAR DATA
PRODUCT MONITOR (3 EACH)
GVAR FORMATTED DATA (3 STREAMS)
IMAGER & SOUNDER BIT-SYNCHRONIZED DATA (3 STR)
GOES-BUS INTERFACES (6) (RANGING)
AUXILIARY DATA
AUXILIARY PORT
SENSOR PROCESSING SUBSYSTEMS (3 EACH) (SPS)
IMC & LANDMARK MEASUREMENTS
IMC & LANDMARK MEASUREMENTS
ORBIT & ATT TRACKING SUBSYSTEM (2 EACH) (OATS)
GVAR SIMULATOR (4 EACH)
O & A SETS
RANGE/STAR MEASUREMENTS IMAGER/SOUNDER INSTRUMENT TELEMETRY
RANGE/STAR MEASUREMENTS REQUESTED SPACECRAFT TELEMETRY
O & A SETS, IMC COEFFICIENTS, NLUTS
GVA SIMULATED DATA (GOES-BUS)
O & A SETS, IMC COEFFICIENTS
PM TEST INPUT
SPACECRAFT TELEMETRY
CDA GIMTACS EQUIPMENT
RANGE/STAR MEASUREMENTS REQUESTED SPACECRAFT TELEMETRY
ORBIT & ATT TRACKING SUBSYSTEM (BACKUP)
SOCC GIMTACS EQUIPMENT
* OIS COMPUTER
DENOTES GFE EQUIPMENT

Substantial Improvements In Capabilities Over Current System Include:

- Realtime radiometric data calibration with extensive statistical archiving.
- Integrated orbit and attitude determination for improved Earth location accuracy.
- Image motion compensation support for image co-registration over full 24-hr. periods.

GOES IJK/LM Operations Ground Equipment Is an All New System for Processing Imager and Sounder Data.

- OGE accepts raw Imager and Sounder data from the satellite for processing; processed data are transmitted to NOAA for uplinking and rebroadcasting, via GOES satellite, to primary users.

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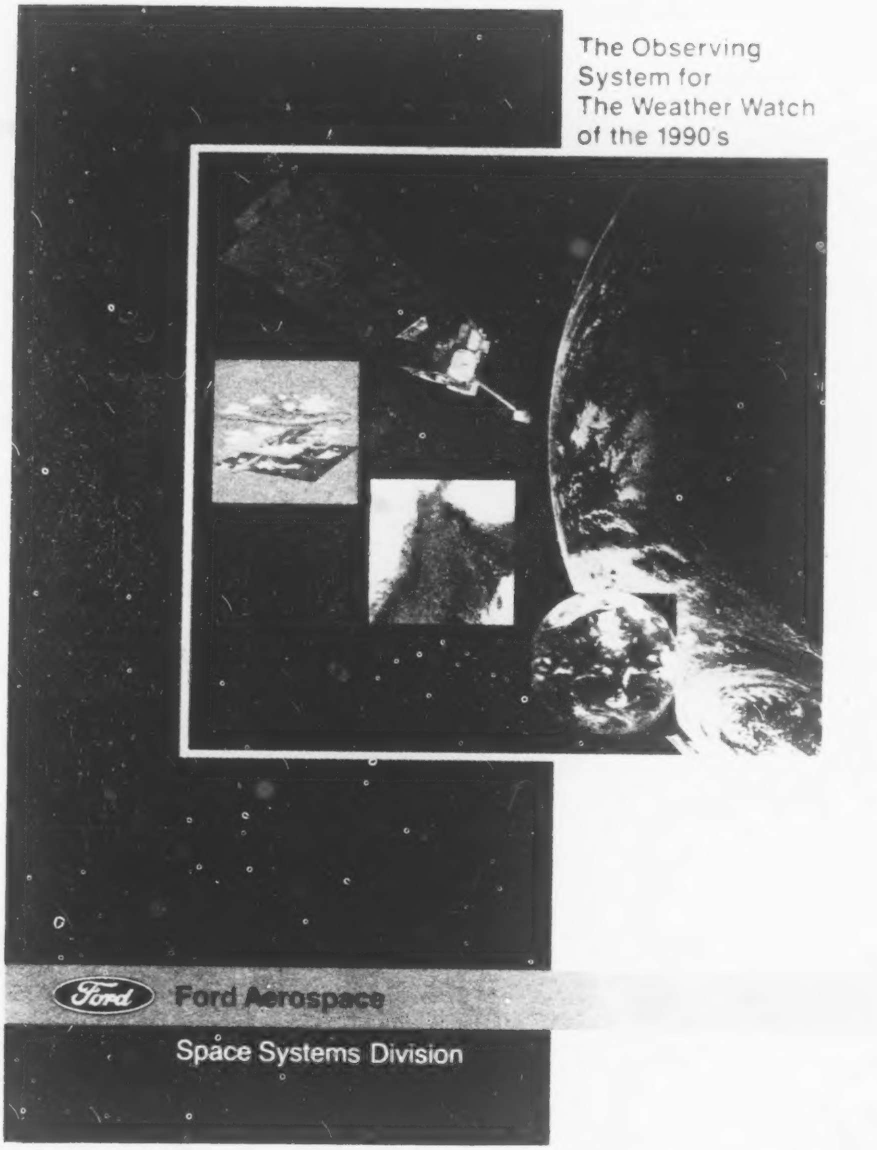
- Installed at NOAA Satellite Operations Control Center (SOCC), Suitland, MD, and NOAA Command and Data Acquisition Station (CDAS), Wallops Station, VA.
- Consists of 11 Gould 32-67 computers, applications software, and custom special-purpose interface boards.

OGE PROVIDES SIX PRINCIPAL DATA PROCESSING FUNCTIONS

- Radiometric Calibration
  - Sensor Processing Subsystem (SPS) calibrates the radiometric data.
  - Compensates for instrument detector thermal and aging effects.
  - Produces a consistent numerical representation of instrument detector radiance values.
- Earth Location and Gridding
  - SPS annotates retransmitted data with precise Earth latitude/longitude for each Sounder pixel
  - SPS annotates retransmitted data with precise orbit and attitude information for Imager pixel earth location calculations by the user.
  - Standard overlay added to data provides visible geopolitical boundaries and latitude/longitude grids.
- Orbit and Attitude Determination
  - Accurate estimates of satellite orbit and instrument attitude are maintained by the Orbit and Attitude Tracking Subsystem (OATS) using:
    - Ranging measurements made by SPS.
    - Star observations performed by Imager and Sounder and extracted from raw data by SPS.
    - Landmark location data obtained from Product Monitor (PM).
  - OATS computes Image Motion Compensation (IMC) coefficients used to adjust instrument mirror scans which compensate for satellite orbital and instrument attitude motion allowing image co-registration to be maintained over a full 24-hr. period.
- Product Monitoring
  - PMs monitor, in real time, quality of retransmitted data.
  - PMs at SOCC monitor retransmitted data downlink.
  - CDAS PMs can monitor both uplink and downlink retransmitted data.
  - Data can be selectively stored on disk for later playback.
  - PMs provide operator assisted landmark identification for supporting orbit and attitude determination.
- Data Simulation
  - OGE Input Simulator (OIS) provides simulated raw instrument data for system test & integration, diagnosis & troubleshooting, and operator training.
  - OIS serves as backup OATS if communications outage occurs between SOCC and CDAS.
  - GVAR Simulator provides test data for product monitor input and users.
- Diagnostic Telemetry Data Processing
  - OATS provides fast Fourier transform and other processing of diagnostic data from on-board angle detection sensors and digital integrating rate assemblies.
  - Detects mechanical resonance disturbances in imagery data due to mechanical motions in the satellite.

Ford **Ford Aerospace**, Space Systems Division, Palo Alto, CA 94303-4697, Phone: 415/852-6989



The Observing
System for
The Weather Watch
of the 1990's

Ford Aerospace

Space Systems Division

GOES

THE GOES IJK/LM PROGRAM: NOWCASTING FOR WEATHER WATCH 2000

The U.S. Geostationary Operational Environmental Satellite (GOES) system is entering a new era of greatly improved operational service. As this era unfolds, the meteorological community and atmospheric scientists of the Western Hemisphere will gain access to observation and measurement data that are more precise and timely than ever before possible.

Inaugurating this improved capability is the deployment of a new generation of GOES satellites, designated GOES IJK/LM. These advanced satellites enhance the GOES system capacity to continuously monitor and measure dynamic weather events in real time, a capability which we call *nowcasting*.

Designed and built by Ford Aerospace for the National Oceanic and Atmospheric Administration (NOAA) under technical guidance from NASA, the IJK/LM series introduces two new features to the GOES system: flexible scan control, enabling small area coverage for improved short-term weather forecasts over local areas; and simultaneous and independent imaging and sounding. In addition, GOES IJK/LM enhances in situ measurements of the solar-terrestrial electromagnetic environment.

These important improvements are made possible by Ford Aerospace's flight-proven design utilizing a 3-axis, body-stabilized satellite. This configuration allows the satellite sensors to continuously "stare" at the Earth, in contrast to the current spin-stabilized satellites which allow views of the Earth a maximum of 5 percent of the time.

Ford Aerospace, a wholly owned subsidiary of Ford Motor Company, has been a leader in applying advanced technologies to the geostationary satellite Earth observation mission. In the early 1970's, Ford Aerospace designed and developed for NASA the first two operational prototypes, called Synchronous Meteorological Satellites, followed by three operational spacecraft, the first of the successful Geostationary Operational Environmental Satellites: GOES 1, 2, and 3. These five spacecraft initiated the operational observation and measurement of rapidly changing weather phenomena in the continental United States, including major areas of the Pacific and Atlantic Oceans. Now, with the advent of the GOES IJK/LM series, many innovative designs and advanced technologies are being integrated by Ford Aerospace to provide significantly improved environmental sensor pointing accuracy, enhanced reliability, and assured flexible growth to incorporate future needs.

GOES IJK/LM satellites are the prime observation platforms for nowcasting during the weather watch of the 1990's and are important forerunners to the proposed Mission to Planet Earth.

THE GOES IJK/LM MISSION

The GOES IJK/LM system significantly upgrades and expands NOAA's capability to provide the data needed for more accurate short-term weather forecasts. This is especially true for severe local storms and tropical cyclones, two meteorological events that directly affect public safety, the protection of property and, ultimately, economic health and development. GOES IJK/LM also improves operational service for space environment monitoring, while supporting atmospheric sciences R&D into numerical weather prediction models, meteorological phenomena and environmental sensors. To achieve these goals requires more frequent imaging of clouds, monitoring the Earth's surface temperature and water vapor fields, and sounding to determine the atmospheric thermal and vapor structures.

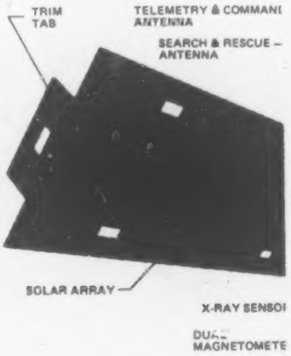
GOES IJK/LM enhances service to the data collection system for receiving meteorological data from Earth-based data collection platforms and relaying the data to end-users. A dedicated search and rescue transponder on board immediately detects distress signals from aircraft and ships and relays them to ground terminals to speed help to people in need. Increased communications capability permits transmission of processed weather data and weather facsimile (WEFAX) for small local user terminals in the Western Hemisphere.

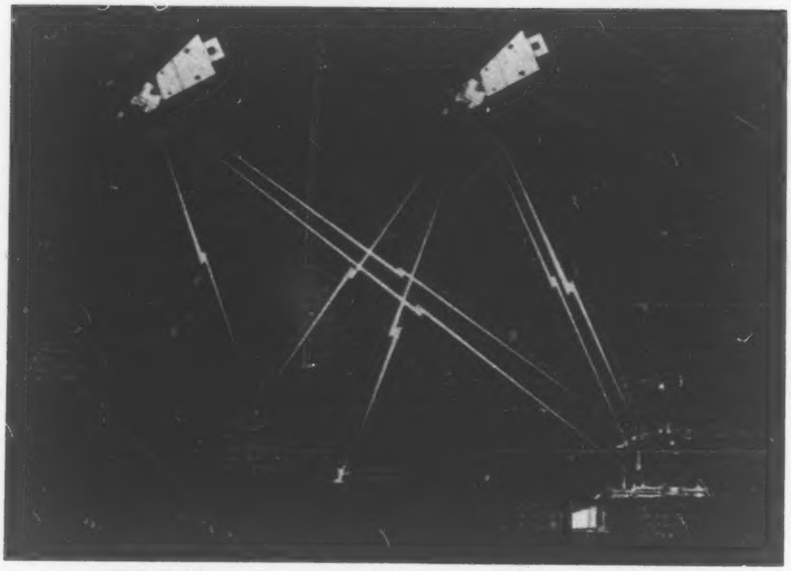
THE GOES IJK/LM SPACE SYSTEM

The new generation GOES satellite is the first 3-axis, body-stabilized, meteorological satellite to be used by NOAA and NASA in geostationary orbit. This stabilization allows the primary mission sensors—the imager and sounder—to "stare" at the Earth.

The satellite design is derived from the flight-proven Ford Aerospace INSAT-1 meteorological satellite, built for the Indian National Satellite System. In continuous operation since 1983, INSAT-1 is the first multi-mission, operational domestic satellite performing meteorology, television broadcast and communications functions.

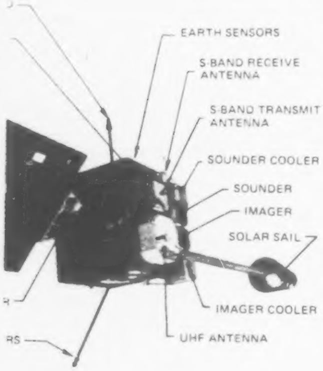
Innovative features have been incorporated into the GOES IJK/LM satellites to provide high volume, high quality data to the weather community. Precision on-orbit stationkeeping, in conjunction with 3-axis stabilization, provides a steady observational platform for the mission sensors, greatly increas-





GOES IJK/LM Satellites. The prime observational platforms for the Weather Watch of the 1990's.

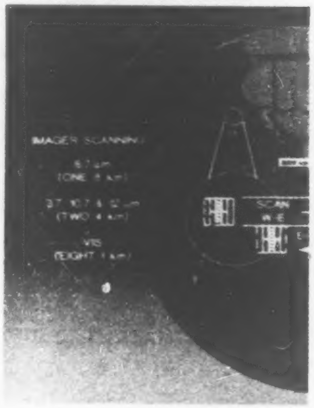
GOES IJK/LM 3-axis stabilization increases mission sensor accuracy for enhanced data quality.


EARTH SENSORS
S-BAND RECEIVE ANTENNA
S-BAND TRANSMIT ANTENNA
SOUNDER COOLER
SOUNDER
IMAGER
SOLAR SAIL
IMAGER COOLER
UHF ANTENNA
R
RS

ing Earth-referenced data location and measurement accuracy over the present system. The capability to more frequently scan the Earth generates 150 percent more images than the current instrument. To preserve data quality while maintaining location accuracy, Ford Aerospace engineers devised an image navigation and registration (INR) methodology that provides daily imaging and sounding data on a precisely located, fixed Earth coordinate grid without ground interpolation. Attention to precision, accuracy and system oriented management all contribute to significantly improving the quality and timeliness of meteorological data products to the user.

The imager and sounder, built by ITT's Aerospace/Optical Division, are designed to optimize the measurements

Rapid scanning of small areas enables improved, short-term, local weather forecasts.


IMAGER SCANNING
6.7 μm
(ONE 8 km)
3.7, 10.7 & 12 μm
(TWO 4 km)
VIS
(EIGHT 1 km)
SCAN
W-E

for the mesoscale and other rapidly evolving meteorological systems that have the greatest impact on short-term weather predictions. The meteorological data product menu benefits greatly from the improved GOES IJK/LM sensors and operating capabilities: imagery in five spectral bands, almost doubled imager infrared resolution, an increase from 12 to 19 channels in the sounder, and greater frequency of operational observations. The introduction of flexible scan control enables rapid, small area coverage, as well as hemispheric and global viewing.

The GOES IJK/LM satellites also carry space environment monitor (SEM) instruments to survey the Sun and its effect on the solar-terrestrial electromagnetic environment. Changes in this "space weather" can significantly affect operational reliability of ionospheric radio, over-the-horizon radar, electric power transmission, and most importantly, the human crews of high altitude aircraft, the space shuttle and the space station. The SEM complement consists of an X-ray sensor, an energetic particle sensor (including a high energy proton and alpha particle detector) and dual magnetometers. The X-ray sensor monitors the total X-ray activity of the Sun. The energetic particle sensor detects the most energetic electron and proton radiation trapped by the Earth's magnetic field as well as the direct solar protons and alpha particles. The magnetometer measures the three components of Earth's magnetic field and the variations caused by ionospheric and magnetospheric current flows.

SOUNDER PERFORMANCE
SOUNDING RATE 172
TIME LOSS INCLUDED FOR CAL
TYPICAL AREA SAMPLE TIMES
3 HR
U.S.
4.5 MIN

Two GOES satellites are positioned in geostationary altitude 35,800 km above the Earth's equator. With identical functional capability, the two-satellite system provides area coverage of about one-half of the globe. Raw imager and sounder data is received at the NOAA Command and Data Acquisition (CDA) station and processed in the Operations Ground Equipment with other data to provide highly accurate, Earth-located, calibrated imaging and sounding data in near real time for retransmission via the satellite to the users. Operational system management and planning are performed by the Satellite Operations Control Center where all elements of the mission are monitored, evaluated, scheduled and commanded via the CDA.

THE USER COMMUNITY BENEFITS

In the present GOES system, a single instrument performs both imaging and sounding on a time shared basis. On GOES IJK/LM, the imager and sounder are separate instruments operating simultaneously, yet independently of each other. Observations provided by each will not be interrupted as in the current situation. The additional time available from separate operation allows continuous and frequent image observation and enables the sounder to provide maximum coverage and radiometric performance without interruption.

The imager produces visual and infrared images of the Earth's surface, the oceans, cloud cover and severe storm developments. Cloud imagery is available to users in mapped format as well as the familiar GOES projection sectors. Mapped products from the imager are available for each imager channel. Two composite images, visible-infrared and infrared-water vapor, are also produced. The higher spatial and spectral resolution for several of the infrared imaging channels, and better radiometric performance than the present sensors, improve quantitative estimates of surface temperature and low level moisture, and monitoring of convective intensity. Spectral and radiometric improvements, coupled with the added channels in the sounder, yield temperature and moisture profiles of greater horizontal resolution, accuracy and coverage than was previously possible.

The prime sounding products are vertical temperature profiles, vertical moisture profiles, layer mean temperature, layer mean moisture, total precipitable water and the lifted index, a measure of stability. Spatial resolution is increased from 14 km to 8 km.

GROWTH FLEXIBILITY

The potential for products obtained from imaging at less than 5-minute frequencies and soundings at less than 1-hour intervals will be evaluated during the first 1-2 years of GOES IJK/LM operations. New data products will be introduced into the GOES system as their usefulness is demonstrated.

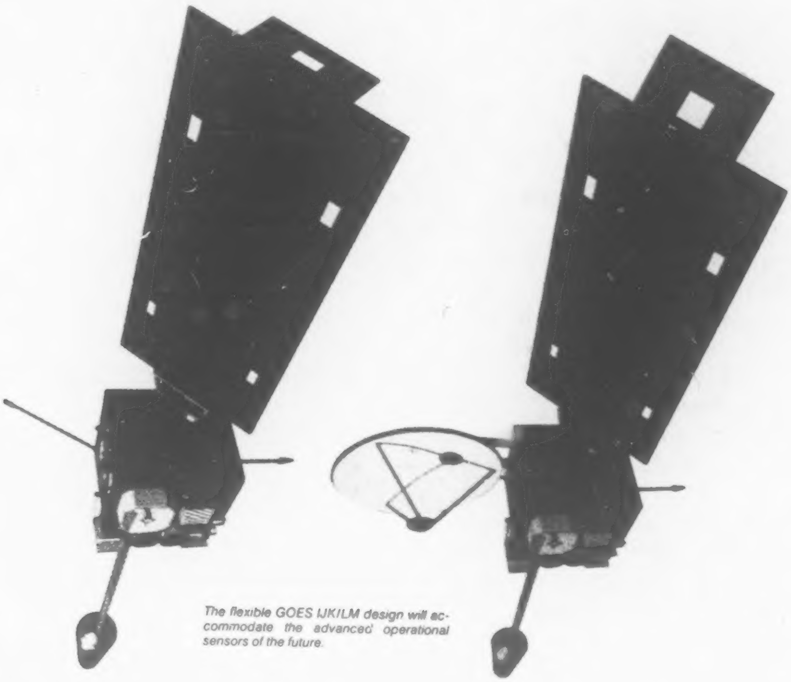
As experience and data become available from the GOES IJK/LM satellites and sensor suite, development and operational evaluation will define additional meteorologic/atmospheric data products. Among the possibilities are moisture corrected sea surface temperatures, total ozone, snow cover, stereo imaging, stereo cloud height computations, and winds over the land for mesoscale weather forecast computer models.

As a platform dedicated to sensor R&D, GOES IJK/LM can facilitate assessment of instrument operational utility and design, definition of additional data products, and establishment of on-orbit support requirements and data communications interfaces for advanced instruments. In this role as a research bus, the satellite can support new, advanced operational or research instruments, such as: solar X-ray imager, active cavity radiometer irradiance monitor, lightning mapper, ozone mapper, microwave sounder, or Fabry-Perot infrared sounder.

The versatility of GOES IJK/LM also extends to participating in space-based applied research of the atmospheric sciences; for example, contributing to the important effort in improving numerical weather prediction models.

The satellite's flexibility encompasses launch vehicle compatibility as well. GOES IJK/LM is compatible with the Atlas/Centaur and can be accommodated by many other launch vehicles.

With designed-in growth flexibility, the new series of GOES satellites are valuable technical and operational vehicles for crossing into the 21st century—the era of the Space Station and the proposed Mission to Planet Earth.



The flexible GOES IJK/LM design will accommodate the advanced operational sensors of the future.

GOES IJK/LM

- Independent and Simultaneous Imaging and Atmospheric Sounding
- 1 Visible and 4 Infrared Channel Imaging
- 1 Visible and 18 Infrared Channel Sounding
- Operational Search and Rescue
- High Sensitivity, Slow Scan System
- Small Area Scan
- Precision Earth Location with Fixed Daily Grid
- Solar X-Ray Imager (L&M)

FUTURE GROWTH FLEXIBILITY

- Microwave Sounder
- Fabry-Perot Infrared Sounder
- Ozone Mapper
- Lightning Mapper
- Active Cavity Radiometer
- Advanced Meteorologic/Atmospheric Data Products

Mr. LEWIS. Thank you, Mr. Stang.

Mr. Sensenbrenner.

Mr. SENSENBRENNER. Thank you very much.

Mr. Stang, is Ford on time in constructing the satellite so that it will be ready to go up before the 1990 hurricane season?

Mr. STANG. I believe the current schedule for Ford and the current schedule for NASA and NOAA is a launch sometime in 1990 and anticipated to be before the beginning of the hurricane season. But that program is constantly under review with them and with ourselves. And since it is a development program, you could still have some delays beyond that.

Mr. SENSENBRENNER. However, as far as you are concerned, the delays will not be Ford's?

Mr. STANG. We hope not.

Mr. SENSENBRENNER. Now one of the problems of being on this Committee is we do not have any scientists that serve as members of the Committee. I practiced law in a community of about 7500 and sometimes scientists and engineers kind of go beyond the country lawyer's logic. Let me ask you to quantify what this new satellite will do, for those of us who are really intimately familiar with space technology.

The bottom line is we want to have more accurate forecasting in terms of storm tracks as well as in terms of the intensity of the storm.

Mr. STANG. Right.

Mr. SENSENBRENNER. It appears to me that this new satellite will do that, but can you tell us how much more accurate you think the new satellite will be over the GOES satellite?

Mr. STANG. From a location of data point of view, which I think is key, the new satellite system and its image navigation and registration system should have improvements by a factor of two or three, over knowing where the storm is located, where the storm is moving to as you take successive pictures of the area, and that is a great aid in knowing where your forecast is going.

Mr. SENSENBRENNER. What about intensity?

Mr. STANG. Intensity, we will be able to have an improvement of two to one in our ability to produce an infrared picture over the existing spin-stabilized series. So for night time operation, that is a rather large improvement. You are going from an eight kilometer capability to a four kilometer capability, rough order of magnitude.

I would think, knowing the—I have been with that satellite system since before it was launched in 1974 and the advances that NASA and NOAA have brought to that system from what was anticipated initially as they introduce the service have been beyond anybody's dreams. They have, over a period 10 to 12 years now, made that the mainstay of forecasting, and I think the new system and the advanced weather data, the advanced accuracy in knowing where you are, what you are pointing at, is going to have a significant input and improvement in forecasting, not only for severe storms of say a thunderstorm nature in your state, but for hurricanes, but for generalized forecasting which is really a key element for the economy also.

Mr. SENSENBRENNER. Mr. Koffler, I would appreciate it if you would answer the question from NOAA's standpoint, how much greater accuracy the new satellite will bring about. And can you also tell us whether it is planned to put this new satellite up on the east coast or the west coast?

Mr. **Koffler**. Well let me answer the second part first. Most likely that new spacecraft will go up on the east coast. It gives us a little better access to the spacecraft, a little better capability to check it out in that position.

On the first part of that question, in terms of the increased accuracy, the ability I think to sound simultaneously with imagery and the ability over the next several years in addition to the introduction of that spacecraft to develop new techniques of using that sounding information in conjunction with the models that Bob Sheets talked about and in conjunction with the new high speed computers that we are talking about, will allow us to make better, more accurate observations of the environment that the storms are in, as well as the model that forecasts better with the information that we will have. It is that capability in addition to the capability of resolution and accuracy that will help us enhance the capability of forecasting those storms, both from the severity point of view as well as the direction.

Mr. **Sensenbrenner**. Can you quantify it like Mr. Stang did?

Mr. **Koffler**. That is a hard nut to crack. I have been schooled as a meteorologist and we have a hard time quantifying a whole lot of things.

Mr. **Sensenbrenner**. Well in Congress we have had a hard time quantifying the budget. [Laughter.]

Mr. **Koffler**. Well if you will allow me to take the same liberties that Congress does in quantifying the budget, I think we are talking about narrowing the error rate in terms of the location of the storm perhaps by a factor of 2. I think that is a reasonable goal. The intensity, Bob was talking about a 20 mile difference which is, you know, a little over 10 percent error in the intensity of the storm that we are talking about. I think a reasonable goal to look at there, a combination of the new observing techniques, the new models, will be another halving of that rate also. I think that is not an unrealistic goal to set for ourselves between now and the year 2000 when this system would be replaced by a future generation system.. That is the kind of thing I think we would be looking at.

Mr. **Sensenbrenner**. Thank you.

Mr. **Lewis**. Mr. Scheuer.

Mr. **Scheuer**. Thank you, Mr. Chairman.

Mr. Koffler, we have had testimony before our Subcommittee in recent days that we ought—it was suggested we go to England and look at the British system of weather reconnaissance reporting. Are you familiar with that system that is located about an hour's drive outside London?

Mr. **Koffler**. Are we talking about the European Center for Medium Range Forecasting?

Mr. **Scheuer**. Yeah.

Mr. **Koffler**. Yes.

Mr. **Scheuer**. The suggestion was made that they were really operating at the state-of-the-art in a way that we are not. And that we would do well to further the integration between our system and their system, that we would benefit enormously by plugging into their system so that American consumers of weather information of all kinds, across the whole spectrum; industry, agriculture, government, military, newspapers, television stations, radio stations, would all have a vastly improved flow of information that was more accurate and more timely than the information that is available to them now.

Would you comment on this?

Mr. **Koffler**. The European Center for Medium Range Forecasting basically specializes in not the short-term forecast, but the three to five day and beyond forecasting capability. They do, and it is recognized, have the state-of-the-art now in that kind of technology, to a large extent because of the hardware, the equipment, the computing equipment that they have available to them in that Center. This is going to be corrected from our point of view with the Class 7 machine that has been put in the President's budget. The data and the forecasts that European Center for Medium Range Forecasting make are available to the National Meteorological Center here for our use, and for rebroadcast to the community in general. So we are currently making use of that information. The model runs, that the—our National Meteorological Center currently make are now competitive with the model runs in terms of the forecast errors that the European Center for Medium Range Forecasting does.

We do have more weather than the Europeans have, as you mentioned earlier in your discussion. We also have a more advanced observational capability, both with the satellites and with the ground base capability. So I see in the not too distant future where we will clearly outdistance the Europeans in our capability to forecast, both on the short-term as well as on the medium- and long-term, in that regard.

Mr. **Scheuer**. But right now as things stand, you would say that their technology is superior to ours in employing the state-of-the-art technology to a greater extent than we do?

Mr. **Koffler**. Yes. Their weather forecasting is basically a computer bound problem and to the extent you have more horsepower and more engine power in your computer, you are going to do a better job. And they do right now have more horsepower.

Mr. **Scheuer**. Do they record weather systems and weather occurrences on the west coast of Africa?

Mr. **Koffler**. Yes, they do from their geostationary satellite.

Mr. **Scheuer**. Well according to the article that I was referring to on the front page of the local paper, it is our inability with the current single satellite up there to reach the west coast of Africa that is lengthening the period of time that it takes before we can report a weather, a significant hurricane threat. Would it help us if we plugged into their system so that we got that west coast of Africa weather information as quickly as they get it and not have to wait until that weather crosses the Atlantic Ocean to the point where it comes within the orbit or the view or the scrutiny of our single satellite?

Mr. **Koffler**. We currently do that today on what is the low resolution capability of their spacecraft. It is less frequent and less accurate than what we would get from the GOES east that we have.

Mr. **Scheuer**. The GOES east that is not in commission?

Mr. KOFFLER. That is not in commission, yeah.

Mr. SCHEUER. Well I mean we are faced with a condition, I mean we do not have GOES east.

Mr. KOFFLER. Correct. There is currently now underway a program to get the high resolution data from this METEOSAT spacecraft which will be pumped into Dr. Sheets' National Hurricane Center hopefully this summer and that information would be in coincident with the Europeans receiving that same quality of information, so yes, we are in fact on line, on the way to get that information into the Hurricane Center.

Mr. SCHEUER. What is holding it up, why is there a delay?

Mr. KOFFLER. It is just the engineering, building the equipment. There is not necessarily a delay in that regard, we are putting together—we had some test data run through in fact very recently and we will have the system shaken down and running.

Mr. SCHEUER. When will it be running?

Mr. KOFFLER. It should be running before summer. One of the things we are——

Mr. SCHEUER. Can you give me—I mean when does summer start?

Mr. KOFFLER. Summer starts in June with the hurricane season.

Mr. SCHEUER. So you think by the end of May——

Mr. KOFFLER. Yeah.

Mr. SCHEUER [continuing]. It will be in place.

Mr. KOFFLER. One of the things we have to be concerned about is to install a reliable system because a system that delivers data only 80 percent of the time is not an adequate system, we have to get 98-99 percent, and that is what we are working on right now. We know we can deliver it, we are not sure yet—we have not built the system yet to deliver it to the 98 percent point and that is what we are working on.

Mr. SCHEUER. Thank you very much. Thank you, Mr. Chairman.

Mr. LEWIS. Thank you, Mr. Scheuer.

Mr. Stang, on one of your charts with the current GOES system, do I understand that the accuracy on storm location that you are talking about there is 10 nautical miles?

Mr. STANG. On the particular chart that you are speaking of there, our current GOES has an accuracy of approximately 10 and the new GOES—that is in kilometers—and the new GOES is somewhere between two and six kilometers.

Mr. LEWIS. Have you checked with the Hurricane Center to see if their data supports that accuracy?

Mr. STANG. I have not personally checked with them, but it is the requirements that——

Mr. LEWIS. That is the requirements, but I do not believe the data substantiates that accuracy at this point. I would like to ask you and Mr. Koffler some questions. The typical fix differences between satellite and aircraft reconnaissance are 30 nautical miles with 10 to 15 percent of the cases as high as 60 percent—or 60 nautical miles. It is claimed by a number of scientists that no new satellite technologies are coming on line in the next few years or in the near or mid-term that would substantially improve current satellite hurricane fix capability. Would you like to comment on that?

Mr. KOFFLER. Again, there are two problems. One is the capability of the satellite data itself to be located and that is what we see on the chart there, is the ability to mechanically, if you would, locate an individual item that the satellite instrument sees. That is one——

Mr. LEWIS. Could I interrupt you one second?

Mr. KOFFLER. Sure.

Mr. LEWIS. Are we talking about the total storm including the wind fields or are we talking about the eye?

Mr. KOFFLER. We are talking about any particular point, and I was going to get to that point. The eye itself, one of the problems with the satellite technology that we have, and it is not going to change significantly with the new technology, is that the eye is sometimes obscured by high clouds. It is sometimes not well-defined and it is in those instances I think where we see the greatest error and that is not going to be significantly improved. One of the improvements we will have with the new spacecraft and the new instruments is the resolution of the infrared, which will allow us to get a sharper image and hopefully detect what would have been an obscure eye more sharply and more closely and sort of focus, if you would, and in that way to get a better accuracy. So it is the mechanical problem of locating any spot, whether it is the edge of the eye or any little cloud element, and the idea of—to see the eye at all under the obscuration of the upper deck. It takes a fairly intense storm before the eye gets really sharply well defined and in the early stages of development it is very, very difficult to locate the center in most of the storms from satellites and that is why we have the aircraft.

Mr. LEWIS. Mr. Stang, would you like to comment?

Mr. STANG. Yes. I think the other point continuing there is that the difference between the two satellite systems is the ability of the three-axis stabilized to perhaps be a factor of five better, to know where you are pointing and how you are moving from point to point or image to image. Now how well the meteorologist can relate that higher accuracy to the specific location of a thunderstorm top or the formation of a hurricane eye remains to be seen, but it is a significant improvement over the existing series as far as the measurement is concerned.

Mr. LEWIS. Last question, there are several areas where current GOES satellites are ineffective. Storms near the satellite's horizon can lead to position errors due to parallax and the error of location of the eye in weaker systems is considerably larger because the visible sensor works only during daylight hours so you have an error of 15-20 nautical miles. The infrared sensor has a resolution of only four nautical miles with an error up to 20 to 100 nautical miles. Will the next GOES be able to move us ahead in that area?

Mr. KOFFLER. Well we will still have—there is always going to be a problem at the edges and that is why the single satellite activity rather than the two satellite activity exacerbates the whole issue. We will have a sharper—a higher resolution infrared capability and therefore a better ability to detect, but the—on the limb of any system there is going to be more difficulty, so the new satellites will be improved, both by the resolution and the fact that we will have two up, will be the better improvement in that regard.

Mr. **Lewis**. Mr. Stang?

Mr. **Stang**. I agree with that. The ability for any satellite to see at the limb degrades, regardless of the satellite and the only way you solve that problem is with a two satellite system and you eliminate the limits, you have the overlap like I showed you on the chart.

Mr. **Lewis**. That is the purpose of two up there.

Mr. **Stang**. That is the purpose of two. The other key factor is that the current series only has two channels of information for picture taking, whereas the new series will have five. And that means increased capability in the infrared or nighttime capability of producing weather pictures, and I think that is going to have a new dimension of added data that will improve forecasting.

Mr. **Lewis**. I asked you about this question, with the current GOES and let us go into the next series, from my excursions to Oklahoma City, talking to those people out there at the Severe Storm Center, how much consideration has gone into the design and development of new GOES satellites in the area of hurricane work, forecasting, tracking—how much has really been applied to that rather than just a general look-see of the globe, how much has really been put into this area?

Mr. **Koffler**. Let me as quickly as I can go through the process that leads us to developing requirements for new generation spacecraft. We spent well over a year working with the National Weather Service developing requirements and those are what have driven the engineering of this particular spacecraft. That includes requirements both for traumatic storms, which is again another one of the major considerations to the GOES spacecraft, as well as the hurricanes. The increased accuracy was driven both by the location of the tornadic storms and severe thunderstorms which caused the flash floods as well as the requirement to locate hurricanes better. The increased resolution of the infrared sensors particularly was driven also by the needs jointly of the severe storm. We consider—we being NOAA—we consider the geostationary satellites as being basically the weather warning satellites, those satellites which are particularly designed because of their continuous look capability at locating, detecting and measuring severe weather. So we consider the hurricane and the tornado and the severe storm and flash floods to be equivalent in that regard and that is where we develop our requirements from.

Mr. **Lewis**. Mr. Stang.

Mr. **Stang**. I really do not feel qualified to comment on how well the requirements have come. I am aware of the procedure, I know that it does work and I was pleased that Dr. Sheets said if he had only one tool, it would be the GOES weather satellite that he would want. I think that speaks for it quite highly.

Mr. **Lewis**. Colonel Riley, could you give us an update of where we stand in the long-term plans for the next two to five years with the WC-130 program?

Colonel **Riley**. Well Congressman Lewis, I think you probably know some of the history as well as—not better than myself——

Mr. **Lewis**. As usual I know the answer to the question, I just want it on the record.

Colonel RILEY. Yes, sir. When President Reagan's last budget was announced in January of this year, the budget called for the current mix of active and reserve weather reconnaissance units to be continued in fiscal year 1990 and through the middle of fiscal year 1991. At that time when the budget was sent to Congress, we were working under the assumption that we would transfer the responsibility for the weather reconnaissance to NOAA. Subsequent to that budget, two things have happened. Number one, the transfer to NOAA has fallen by the wayside and number two, President Bush has directed Secretary Cheney to resubmit a DOD budget for fiscal year 1990 and 1991. The reduction in the DOD is approximately $6 billion in fiscal 1990 alone and approximately $2 billion of that reduction will come from the Air Force flying. So essentially we are going through the complete cycle that led up to the 1990–1991 Reagan budget but we are going through that cycle again. Force structures are being analyzed and assessed and we have submitted a plan that outlines the transfer of the mission to the Air Force Reserve for continuation of the mission at the mid-1991 year point and that is being scrutinized and looked over by OSD at this time. It will be of course reviewed within the Office of the Secretary of Defense and then OMB and the President himself, and we expect the budget to be transmitted to the Congress later this month or the first part of next.

Mr. LEWIS. It was my understanding in my discussions with acting Air Force Secretary McGovern that we do have a policy established now and apparently we do not have to worry other than making sure that you have the money to do the job in the long-term.

Colonel RILEY. Well sir, for the record, the Air Force has to say that OSD has to approve that policy and that is being scrutinized right now.

Mr. LEWIS. I understand.

Colonel RILEY. There are questions being asked because we—you know the 1990 and 1991 funds were on the basis of the fact that there was going to be no further requirement for the Air Force to do that. Now we are not only asking for 1990 and 1991 funds, but funds beyond that time frame, so they are looking at that rather closely right now.

Mr. LEWIS. We recognize it will be a budgetary item every year.

Mr. SCHEUER. Will the gentleman yield?

Mr. LEWIS. I will certainly yield to you.

Mr. SCHEUER. How old are the WC–130s?

Colonel RILEY. Well sir, I cannot give you an exact answer, I can get you one for the record, but in a rough order of magnitude, most of them date from the early to mid-1960s, but we have only 12 airplanes total. I could give you the exact years for the record if you would like that.

Mr. SCHEUER. So they are a minimum of 25 years old.

Colonel RILEY. Yes, sir, but in terms of flying hours, compared to some of the other earlier models, such as C–130, it is a basic C–130 with some modifications made for the weather reconnaissance mission—in terms of flying hours, they are substantially younger than other C–130s that are in the Air Force inventory right now.

Mr. Scheuer. Well I suppose you could say they are younger than some of the DC-3s that are still flying.

[Laughter.]

Colonel Riley. But they are very well maintained and they go through a regular period of programmed depot maintenance and intermediate inspections on a regular basis.

Mr. Scheuer. There is no question they are well maintained. From the point of view of quality information, would there be an advantage in replacing them with state-of-the-art modern airplanes?

Colonel Riley. Well I would prefer to defer that answer to Dr. Sheets because in this situation he basically sets the requirements for the kind of information that the Air Force is to provide to support the National Hurricane Center.

Mr. Scheuer. To support what?

Colonel Riley. To support the National Hurricane Center. Now we worked rather closely on the Improved Weather Reconnaissance System which is being installed right now on Air Force WC-130 aircraft. With the addition of the Improved Weather Reconnaissance System, it is my belief and understanding that we will have a substantial increase in the quality and the accuracy available to the Hurricane Center to do their job. But the real answer is what is the requirement of the National Hurricane Center. I think that the Improved Weather Reconnaissance System that we have and are currently fielding meets those requirements.

Mr. Scheuer. Dr. Sheets, could you enlighten us on this information?

Dr. Sheets. I think for the next several years that indeed the IWRS system that he is talking about is a major advancement over what we have had in the past. It is similar to what we have in the NOAA research aircraft and as we look into the future, yes, we ought to be looking at higher flying, faster aircraft——

Mr. Scheuer. Well I am looking into the future. I am not saying what we have now is not better than something we had 10, 20, 30 years ago.

Dr. Sheets. As we look downstream 5, 10, 15 years from now, we ought to be looking at different aircraft, different sensors and different capabilities, yes.

Mr. Scheuer. So you believe that—let us put it this way, in the not too distant future we ought to be replacing these WC-130s.

Dr. Sheets. Certainly by the mid-1990s we ought to be developing the new technology from different aircraft and replacing those with different types of aircraft.

Mr. Scheuer. What do you mean by saying in the mid-1990s we ought to be developing that? If we are going to have it in the mid-1990s we ought to damned well start developing it now.

Dr. Sheets. Could not agree more, sir.

Mr. Scheuer. Is that being done to your knowledge, is that kind of research in place?

Dr. Sheets. No, it is not.

Mr. Scheuer. Colonel, do you know if that kind of research is in place?

Colonel Riley. To the best of my knowledge, it is not, sir.

Mr. SCHEUER. Well I would say, Dr. Sheets, we ought to be conferring with you and with the Colonel and other of his colleagues in the Air Force to find out what kind of research should be done to produce what kind of planes, so that they will be in place in the mid-1990s and avoid—I have been coming down here regularly every five years to meet with Tom on one problem or another, right, Tom?

Mr. LEWIS. That is correct, sir.

Mr. SCHEUER. I do not want to come down here in 1994 and have you testify that this is what we need in place in the mid-1990s, next year. Then we all wonder why we were sitting around on our duffs in 1989 and 1990 when we should have been starting the research that would have this kind of aircraft capability in place, on line and in use by the 1990s. Am I off target?

[No response.]

Mr. SCHEUER. I did not hear you.

Dr. SHEETS. Are you speaking to me?

Mr. SCHEUER. Am I off target?

Dr. SHEETS. No, sir—no, sir, I could not agree with you more. In fact we have outlined in a very general form a plan that is in your document there that looks toward the future and indeed it looks at this type of technology that we have on these satellites, takes that same technology and integrates that with aircraft and satellites to give you entire data fields very fast with high performance aircraft rather than just the point values as the airplane flies along, and that would make a major improvement in models as well as in the immediate forecast period. So indeed that is in your document as one of the future things. I did not testify to that, but it is in your document.

Mr. SCHEUER. And it is one of the future things we ought to have, but if we want to have it in the future, we ought to start working on it in the present.

Dr. SHEETS. Yes, sir.

Mr. SCHEUER. We ought to be getting on with that.

Dr. SHEETS. Yes, sir.

Mr. SCHEUER. Thank you very much, Dr. Sheets.

Mr. LEWIS. Thank you, sir. I think Dr. Gray will also be speaking to that.

Mr. SCHEUER. Good.

Mr. LEWIS. Colonel Riley, could you tell me if the 130s, starting with this hurricane season, will have the frequency microwave radiometer for a more accurate detection of surface winds?

Colonel RILEY. No, sir, that is not part of the Air Force inventory. That is on the two NOAA P-3s.

Mr. LEWIS. Is it considered for the 130s at all?

Col. RILEY. No, sir.

Mr. LEWIS. Why not? No request for it?

Col. RILEY. That is absolutely correct.

Mr. LEWIS. So we only have two P-3s that can do this, is that right, Mr. Koffler?

Mr. KOFFLER. [Nods head affirmatively.]

Mr. LEWIS. Is that not important data?

Mr. **Koffler**. Yes. I would again perhaps defer to Bob Sheets in that regard. The wind surface data clearly would be an item that would be useful in the model.

Mr. **Lewis**. Come back, Dr. Sheets, and sit next to the Colonel here, he needs some help.

The first question I asked when you were out of the room, sir, was about the frequency microwave radiometer, would it be in the 130s for this next season and the Colonel answered no, it is only in the P-3, you have two P-3s and I asked him if there was any indication they would install them and why not and he said no and Mr. Koffler pointed out that we should ask you. So you are it.

Dr. **Sheets**. Yes, sir, it is an experimental kind of instrument to try to measure surface winds and of course that is what we try to get to, to get down to the surface winds and measure those. And the NOAA research people have been doing that and Dr. Peter Black will be testifying a little bit later to give you some information on that. As far as I am aware, there are no plans at the present time to put that on the operational aircraft, but part of this has been the uncertainty in this whole reconnaissance program for sometime here over the past few years, and indeed the Congressman from New York is entirely right, as a result of some of those things, advancements have sort of leveled out. In other words, the IWRS program was put together several years ago and we are seeing the fruition of that now. If we are going to see something in the mid-1990s we have to start now. And this is just another one of those things that has sort of gone by the board because of the uncertainties in the reconnaissance program.

Mr. **Lewis**. Is this not an important data point that you really need?

Dr. **Sheets**. Surface winds are one of the critical factors. In fact, we get more complaints from our engineering friends and others over the ability to infer the surface winds themselves, whether you have strong showers, thunderstorms, and it is different there than it is if you have a Gloria moving over colder water and all those conditions. So indeed those are some of the measurements that would be quite helpful.

Mr. **Lewis**. One criticism of the 130 program is they have not flown high enough to give you accurate information and again, we have not had the mid-level flights. Do you program that out of the National Hurricane Center? Are the 130s not capable of doing that, or is it just that they do not do it?

Dr. **Sheets**. Well there is conflicting kind of interest we have and a very limited resource to work with. The critical factors that we use in the warnings in the 12 to 24 hour time frame, maybe even up to 30 hours in our warning process, is the wind field in the immediate vicinity of the center of the hurricane, the core of the hurricane, its location. So that is what we use the C-130s primarily for. We use the satellites in inferring the fields around the hurricane, so they are really very complimentary in that fashion because a satellite can look over the entire hemisphere and get patterns all around the hurricane, where the aircraft cannot do that. The aircraft cannot fly fast enough to be able to measure those things around it. Now the depth of the atmosphere, you are exactly right, we have had problems in the middle part of the atmosphere and even on up into the upper middle parts of the atmosphere in getting information to go into our numerical models. And I think Professor Gray is going to talk about that a little bit later and what that may mean.

Mr. **Scheuer**. Will the gentleman yield?

Mr. **Lewis**. I will yield to the gentleman from New York.

Mr. **Scheuer**. I have heard that there is a problem that the WC-130s are not flying low enough. Now the Chairman says that are not flying high enough. Is it both of the above?

Dr. **Sheets**. It is both of the above. I flew into hurricanes for about 16 years and I do not want to get down there too low myself. But the Air Force does have a program that once the winds get above 80 miles per hour, they normally go to 10,000 feet. They have done much better in recent years in going up there, but if I were then with the experience levels that are there and the training levels and the changing situations that exist with the Air Force crews, I think they do the right thing. If you have a strong hurricane like a Gilbert, it really does not matter so much whether you are at 10,000 feet or 1,500 because the winds basically go all the way to the surface. It is those conditions like Gloria was as it moved up near your state, sir, where you had cold water and you get a very stable kind of condition near the surface that indeed it is difficult to infer what those winds are below the aircraft. So these frequency microwave radiometers and other types of devices would be very helpful in those particular situations.

Mr. **Scheuer**. And low flying aircraft.

Dr. **Sheets**. And low flying. Our NOAA research aircraft, we used to go as low as 500 feet, but I did not enjoy that.

Mr. **Scheuer**. Thank you very much.

Mr. **Lewis**. Thank you, Mr. Scheuer.

Questions from the staff?

[No response.]

Mr. **Lewis**. Well again, thank you gentlemen for attending the hearing. Your information is valuable in the overall synopsis of the hearing, and we appreciate your time.

Mr. **Scheuer**. I thank the extended panel.

Mr. **Lewis**. Our next panel will be our TV meteorologist panel. John Zarella, Cable News Network from Atlanta, Georgia; James Reif from WINK-TV, Fort Myers, Florida; Art Horn from WPTV Channel 5, West Palm Beach and John Levitt, WPBR, Palm Beach.

Gentlemen, your entire written statements will be entered in the record and you may summarize your testimony for the Subcommittee. John Matthews was here, is he still here?

Voice. He has left.

Mr. **Lewis**. Okay, I was going to invite him to joint the panel.

STATEMENTS OF JOHN ZARELLA, CABLE NEWS NETWORK, ATLANTA, GA; ART HORN, WPTV, CHANNEL 5, WEST PALM BEACH, FL, AND JOHN LEVITT, WPBR, PALM BEACH, FL

Mr. **Horn**. Thank you very much for inviting me.

From the viewpoint of the television meteorologists, we obviously are the conduit to the public when it comes to all this information. The National Weather Service has its way of disseminating their information to the public through the various forms of media and I think one of the most effective is television. So we have a big responsibility when it comes to these hurricanes, to try to get the word out to people in the most credible manner.

In my statement, what I have talked about is principally from the viewpoint of south Florida, that I think it is important that we do maintain the consistency of information that we have had in the past. We have come to rely on the hurricane hunter aircraft for the kind of information they have. We have come to rely on the satellite data. So I think it is important in terms of a credibility point of view that we continue this into the future in a consistent manner.

The public perception of the danger from hurricanes I think could be adversely affected if we do not maintain that consistent flight of hurricane hunter planes and with the good satellite data that we have. In other words, I think that we need to maintain the quality of information so that people do not get the feeling that the hurricane threat is in any way reduced.

It is pretty obvious from what Dr. Sheets has said and what I think the general perception is that south Florida, particularly from the Keys up through Stuart, Vero Beach has not experienced a major hurricane in a very long time and with all of the population increase that we have seen, we are extremely vulnerable now to a major storm. If you live in this area you know that a lot of people come from other parts of the country. Somebody from Chicago does not understand the threat of a hurricane like someone who lives here and has lived here for a long time. So we are in a constant educational process as well as having the responsibility to warn people about the immediate danger of an impending storm.

So that is my concern, that we continue with the good flow of information that we are getting and that we keep it going into the future.

[The prepared statement of Mr. Horn follows:]

P.O. BOX 510
PALM BEACH, FLORIDA 33480
407 655 5455

WPTV5

To whom it may concern,

Good afternoon to everyone. My name is Art Horn and I am the Meteorologist for WPTV channel 5 in West Palm Beach. Hurricanes are a very real threat to our coast line, marine areas near the coast and land areas inland from the coast. From my point of view which, is South Florida, we need all the help we can get when dealing with such powerful and erratic storms.

At no point in our history have we been as vulnerable to hurricanes as we are right now here in South Florida. No major storms have hit here in almost 30 years. Combine this with massive coastal development and a population that has never been through a hurricane and you can see that we have a major credibility problem down here. During hurricane season I try to make it clear to people that hurricanes are dangerous and that they do hit this part of the country from time to time.

If we do away with our hurricane Hunter Air Craft I believe we will be sending the wrong message to a vulnerable population. Many people who live in South Florida have moved here from places not affected by hurricanes.

If I have to tell them our aircraft will no longer monitor these storms, people may begin to think that a hurricane is no more dangerous than a midwest blizzard. Let's find a way to keep our Hurricane Hunter Air Craft up there. Satellite pictures are of great value when monitoring hurricanes in remote areas of the ocean but the data we get from the planes tell us much more about the strongest point of a hurricane.

Its this detailed information about the storms center that is so valuable to Meteorologists, most of all when the storm is near a land area. I would not want to try to warn the public about the strenght of a hurricane by having to guess how strong it is by looking at satellite pictures. At this time I think we do a good job in monitoring and tracking hurricanes but with so many people living on the coast here in South Florida I believe we need to, at very least maintaine our current capacity.

Sincerely,
Art Horn
Art Horn

Mr. Lewis. Thank you, Art.

Mr. Zarella. I would like to talk just briefly about the international responsibility that has developed recently because of some of the technology advances that we have seen. If it is not in hurricane forecasting, it certainly is in television, as you are well aware.

And I think to do that, I want to just background you briefly on the Gilbert experience which is pretty much what has gotten us all here together today, to some degree.

It was on September 10 and it was 5:00 a.m. in the morning, hurricane Florence was moving up the Gulf coast about to hit in the New Orleans area. We were at the Hurricane Center preparing to do a live broadcast of that storm. While we were there looking at your GOES satellite photographs of the Caribbean, there was a blob as we would call it in the colloquial, forming southeast of Puerto Rico and it was Bob Case, the forecaster on duty at that time, who took a look at it and said it is awfully interesting, the weather conditions are all right, the water temperature, the surface temperatures, the upper level winds are all right, it sure could be a big one. He did not know at the time that what he was looking at was ultimately going to be hurricane Gilbert which is now considered the greatest storm of the century.

My belief is that it was not necessarily from what he knew, the facts that he was getting, the technical data that he was getting—that had a great deal to do with his decision and why he was saying what he was saying, but it was years of experience that led him to that decision that boy, this could be a big one.

Well during the next six days we broadcast live from the National Hurricane Center more than 60 times, including 10 additional times in Spanish. The point being that we feel that we and the National Hurricane Center certainly have an international responsibility. So far today we have heard about what effect a storm can have on the United States. Well we are forgetting about the Caribbean and we are forgetting about Latin America and how important they are and how they rely on the National Hurricane Center for information and forecasting of storms. And a good example being that they rely on CNN because of satellite technology for a great amount of their news.

Evacuation cues, for example, are coming in some instances directly from what they are hearing broadcast on CNN which is being broadcast directly from the National Hurricane Center. The Cayman Islands is a good example. Many people got off the Cayman Islands because of the broadcasts they were hearing on CNN. They got off the island because there was a good chance that this killer storm was going to hit the Cayman Islands. Fortunately it did not hit the Cayman Islands, but there is an example of a direct broadcast relation and how we can affect people in these places.

In Costa Rica during hurricane Joan, the President of Costa Rica, Oscar Arias called Dr. Bob Sheets and said please have the people at CNN tell our people, because there is a lot of misinformation getting out, that the storm is not an imminent danger to us. And of course we did cooperate on our Spanish network and got that broadcast out.

What I am trying to say to you is that the direct broadcast now of—because of satellite technology that we have and the fact that satellite dishes are springing up all over the world, that people are getting their news and their information very much directly, more directly now than they ever did before, a lot quicker than they ever did before. We can see when we are broadcasting out of the National Hurricane Center, we can watch a storm on the satellites, we can see it moving, we can look at the Doppler radars and we can see cross sections of the hurricanes. We can do all of these kinds of things and we can show it to the people, we can educate the people as to why a hurricane is bad, why you need to move out of the way and get out of the way of a hurricane. But we still cannot say exactly with any certainty where that hurricane is going, which is the ultimate question that someday hopefully will be answered.

All of these things that we can do, we do because of the satellites and we do because of the hurricane reconnaissance planes that we have out there.

You have also put a great responsibility on the forecasters at the National Hurricane Center, a greater responsibility than they ever had before. They always had the responsibility to warn these islands and these countries, but now the perception in those islands and those countries is different because they are seeing these people on the air live saying that storm is coming. Before, the information was going first to their governments and then to the people, but in many cases now it is not quite like that. The information is being broadcast directly. Before they know about it in any other fashion, they are hearing about it on television. Mistakes cannot afford to be made in that particular case.

If, for example, you as Dr. Sheets said, take a hurricane of 95 mile an hour winds or one that has 105 or 110 mile an hour ones, you are not sure which is which and you go on the air and you broadcast for the lower case scenario and it turns out to be the higher case scenario and people in these countries and on these islands have not taken proper precautions because of that, you run the risk of an international incident, that we are the ones responsible for perhaps killing hundreds, if not thousands, of people. It is a scenario that I do not think that we, until this year with hurricane Gilbert, fully saw as coming.

At the Hurricane Conference yesterday, folks from Barbados, from the Cayman Islands and from Jamaica all came to me and said we rely on you people for the bulk of our news and we certainly did during hurricane Gilbert. We knew we had that responsibility, but we did not know to what extent our responsibility was.

Finally, on the other hand, you can use it as a great tool as well. If we give the hurricane forecasters the tools, if we keep up the current levels and then take it into the next generation as it should be taken, we can more accurately predict, we lessen the risk that somewhere someday someone is going to make a catastrophic mistake in a forecast. If we keep those hurricane hunter planes flying in there more frequently, we lessen the degree of error. We also are fostering good will in those places, in those countries, which is all part of our responsibility, not just CNN but part of the mandate and the charter of the National Hurricane Center.

Mr. **Scheuer**. Of course you are an extension of the National Hurricane Center.

Mr. **Zarella**. Exactly. That being the point, we are.

Mr. **Lewis**. Thank you, Mr. Zarella. Mr. Levitt.

[The prepared statement of Mr. Zarella follows:]

TESTIMONY

By: John Zarrella, Bureau Chief CNN
Before: Subcommittee on Natural Resources, Agriculture Research and Environment

Mr. Chairman and Members of this Committee:

It was five a.m. on Saturday, September tenth. We were about to broadcast live from the National Hurricane Center. Hurricane Florence, a minimal storm, was just making landfall on the Gulf coast. As forecaster Bob Case and I looked at the satellite images of the caribbean, he noticed a cluster of clouds; a large area of disturbed weather. But, for our six a.m. broadcastthe focus remained Florence. That other area, southeast of Puerto Rico, would have to wait until Florence was inland and the Hurricane Center passed-on that responsibility. It would not take long.

By seven a.m. Mr. Case was looking with keen interest at the blob in the caribbean. I asked his opinion. He said that the conditions were all favorable for development; water temperature, surface pressure, upper air winds. It could become a large storm, he said. Mr. Case didn't know how right he was. That blob was the infancy of Hurricane Gilbert.

Mr. Case's opinion was based partially on what he knew were the conditions in that part of the caribbean and, on a satellite image. But, I believe his opinion was based primarilly on years of experience. From that point on, for the next four live broadcasts that day, we devoted our time to what was a great storm developing before our eyes. For the next six days as Gilbert grew and grew and trudged across the caribbean and into the Gulf of Mexico, CNN broadcast live more than sixty times from the National Hurricane Center. Add to that another ten broadcasts in Spanish on our Spanish network.

As with many hurricanes, Gilbert crossed the path of several nations with varied languages. It is our responsibility as an International network to make sure the word gets out and is understood. Because so many people on the caribbean islands and in Mexico and Central America get their world news from CNN off satellite dishes, it makes our role all the more important.

Countless times during Hurricane Gilbert and then again during Hurricane Joan, which devastated parts of Nicaragua, our office received calls from people in the caribbean and Latin America asking us to keep up the coverage because it was the only way they were getting reliable information. During Hurricane Joan, the president of Costa Rica Oscar Arias, even appealed to Dr. Bob Sheets, Director of the National Hurricane Center, to have CNN broadcast to his people that Costa Rica was in no imminent danger. There was just too much misinformation getting out. That broadcast was made on our spanish network.

The reason, Mr. Chairman and members of the committee, that so many people come to rely on us is simple. Our broadcasts were frequent and came directly from the source. When the forecasters at the National Hurricane Center were live on CNN, they were talking directly to the people in the watch and warning areas. Although forecasting the track of a hurricane is an inexact science, the people in those areas had a pretty good idea whether the storm was coming.

TESTIMONY CONTINUED

But because the technology is not there to predict exactly where a storm will make landfall, there are occasions when populated areas must be evacuated simply because the forecasters just don't know with one hundred percent accuracy whether the storm will hit. The Cayman Islands, during Hurricane Gilbert are a perfect example. Hundreds of people fled the islands on emergency flights because it was believed that Gilbert had a good chance of passing directly over them. Ultimately, the storm passed to the south and the Caymans sustained only minor damage. Most of the people there were relying on CNN for information and based their decisions to leave on our reports from the Hurricane Center. I do not doubt for one minute that if a sufficient level of funding were provided for hurricane research and technology, that all the guess work could be replaced by one hundred percent accuracy. This would, in the long run, eliminate tens of millions of dollars in needless evacuations.

I have covered hurricanes for the past ten years. But, this last season, as volitile as it was, gave me a greater appreciation for the men and women at the National Hurricane Center and what they do with truly limited resources and technology. Tens of thousands of people can make a decision on what to do in the face of a hurricane based on what we report. Never once have I put a Hurricane Center forecaster on the air fearing his call might be wrong.

But CNN is certainly not the only media outlet. There are dozens and dozens of local television stations and the other three networks that broadcast in hurricane prone areas along the U.S. coastline. They have their own meteorologists who base their forecasts, in most cases, on the guidance provided by the Hurricane Center. Although meteorologists, these people are not hurricane specialists and on occasion misinformation gets out. Any misinformation in the face of a powerful storm can cause a panic. Here again, CNN's role of directly broadcasting from the Hurricane Center takes on a heightened sense of urgency. That did happen during hurricane Gilbert. We don't pretend to reach all the viewers or all the emergency management organizations but, hopefully the right word gets spread as rapidly as the rumors.

In this day and age of instant communications, there is a great deal at stake in terms of lives and property when a forecaster is speaking to not one but many nations. No one can predict how many hurricanes will form this year, how strong they'll be or where they will go. So, it is imperative the National Hurricane Center be afforded all the resources and technology possible, be it hurricane hunter aircraft or sophisticated satellites and instrumentation to meet a truly heavy responsibility.

In closing, let me just remind you of the 1987 season. Hurricane Emily had just passed over the Dominican Republic. The mountains pretty much tore it apart. But, during the night, the storm suddenly regenerated, picked-up forward speed and plowed straight for Bermuda. If it hadn't been for the fact that a hurricane hunter aircraft was in the storm at the time of its rebirth, the warning to that island might have come too late. It is more than just a possibility that someday another storm will do the same thing only its target will be the United States coastline.

Mr. Chairman, members of the committee, thank you for this opportunity.

Mr. LEVITT. Thank you, Mr. Chairman.

My two colleagues here deal with visual images and pictures and John has been out covering stories and can show the damage and can show the wind whipped Gulf of Mexico or Caribbean Sea. I deal with radio at WPBR and we depend on the spoken word. And as many of you know, radio is usually the first line of defense when a local disaster happens or impending, people will turn to their local radio station.

I am very concerned here in Palm Beach County as a broadcaster in Palm Beach County and a journalist, that we have a very critical hurricane problem. It exists today although there are no storms on the horizon, and that is something that my college Art Horn and John Zarella both spoke about, we have it here in Palm Beach County. It is the credibility problem. Eighty five to 90 percent I believe by local estimates as well as the National Hurricane Center of the people that you see on these barrier islands—look out the window right now—have never experienced a hurricane, a real hurricane, although many of them think we have. We have some cruel hoaxes played on us recently by nature. In 1984, a tropical storm named Isadore came by and in 1987 in October a very weak hurricane that was collapsing as it passed by, named Floyd.

Dr. Sheets and his staff did what they had to do, they put up a warning. We at WPBR and the rest of the news media in Palm Beach County had to report hurricane warnings were up. It was our job to tell them that yes, it is a hurricane but it is falling apart, it is a very weak hurricane. The problem we have, people think they went through a hurricane, there were hurricane warnings up here in 1987 in October. It was Floyd. They will say now that was nothing, we have had summer thunderstorms in New York, Congressman, or in Wisconsin, that are far worse than that. What are these people bellyaching about.

So in radio as in TV, as Art and John, we need all the information. In our newsroom we have the facilities, we are a CNN affiliate, we deal very closely with John's office in Miami. The satellite helps us and helps us a great deal, but the aircraft, the Air Force reconnaissance planes are, in my opinion, the first line of defense and will help me with my credibility when I have to deliver a watch or a warning.

Earlier in this discussion, Dr. Sheets was asked what about the problem of cavalier weather forecasters or cavalier journalists. I will say, as I know with the colleagues here, we put nothing on the air that does not come directly from the National Hurricane Center.

Mr. SCHEUER. Excuse me. Will you describe what you mean when you talk about cavalier broadcasters?

Mr. LEVITT. Cavalier broadcasters, yes, Congressman, there are private journalists, there are private forecasting groups, as Dr. Neal Frank spoke about at the Hurricane Conference in Miami, who will interpret the data differently and put out their own forecasts. They are experienced meteorologists in many instances and they are looking at the homogenized data that I assume comes out of the National Hurricane Center. I know having worked at the National Hurricane Center a number of years ago, I know all of the raw data that goes in there. I know the people, the forecasters, I have known Bob Sheets for almost 20 years. Dr. Peter Black, I have renewed an acquaintance with him today. Dr. Frank, Bob Case and some of the others.

The technology, the information that they get, the various computer modeling forecasts, we—and again it is the policy of WPBR, as I know with Art and with John—we stick to what comes out of the National Hurricane Center, but then it is our job as broadcast meteorologists and journalists to explain it and to get the people motivated.

Art mentioned just a couple of moments ago, we are concerned. As I said, we have a critical problem here, to motivate people, a credibility problem. We have two sides of this, gentlemen. We have people who will be scared to death if we say there is a tropical depression out there with 25 knot winds, and we have people who will be skeptical, say they have been through a hurricane like Floyd or Isadore, even if it is a Gilbert size, and will say you are crying wolf. It is our job as broadcasters, working with the folks at the National Hurricane Center, to motivate people. We have thousands upon thousands of people on these barrier islands. My radio station is 50 yards from the Atlantic Ocean on Lake Worth Beach.

We have a problem. We need every piece of information that we can get. The reconnaissance aircraft are absolutely needed. And that is why I am very proud to say to you gentlemen that WPBR, along with Congressman Tom Lewis, when this was announced at last year's Hurricane Conference in Atlanta, undertook a program with our listeners to educate and to inform you in Congress that the planes had to stay. Otherwise, they would have been gone at the end of fiscal 1990.

We started a campaign in our community, a postcard writing campaign—we printed these cards—to the Secretary of Defense. They were signed by over 30,000 people here in Palm Beach County, listeners to WPBR. I went up to Washington, I alerted Congressman Lewis what was going on, and as Congressman Lewis said this morning—and I will congratulate him on receiving the Legislator of the Year award from the National Hurricane Conference—Gilbert helped us.

We need, as broadcast meteorologists every piece of information we can get, and they certainly need it at the National Hurricane Center. There is an old theory, gentlemen, 12 hours of daylight—that goes back to when I was a kid growing up down here—if we could put hurricane warnings up 12 hours of daylight, everything is going to be okay. That may have worked for Cleo in 1964 or maybe even Betsy in 1965. With the hundreds of thousands of people on the barrier islands, we need, I think in Palm Beach County, B.T. Kennedy, our Emergency Manager estimates, 27 to 30, 31 hours to evacuate properly all of these barrier islands that you can see, and get these people off safe.

You heard what Dr. Sheets has had to say about the intensity of hurricanes. We need all the information we can get. The satellites are great and I would second what Dr. Sheets says. If I had but one tool, I would want a GOES satellite that covers from Africa to the Caribbean and to the Gulf of Mexico. But so many times, we saw this last hurricane season, you can get some cloud developments and most of that development—it looks very impressive, sometimes it is at the mid-levels to upper levels from say 700 millibars on up to 500 millibars. At the surface there is nothing.

The reverse can be true. I remember hurricane Celia in 1970. Just before it went into Corpus Christi, in the very lowest levels of the atmosphere and Dr. Sheets can correct me, it has been a long time since I read the paper on this—a rapid intensification began just before that storm went ashore. Had it not been for the aircraft—this intensification took place I think at 900 millibars, 2-3,000 feet—it would not have been picked up by a satellite. The winds increased significantly.

What I am saying is, the people sitting here, it is our job to make all the fine work that Dr. Sheets does reality, we have to motivate people. We need all the help we can get. We need the reconnaissance aircraft well through this next decade and on into the next century.

Thank you very much.

[The prepared statement of Mr. Levitt follows:]

The hurricane threats here in Palm Beach County is at an extremely critical level. As a broadcast journalist and meteorologist my job will be tougher this year than last, because Palm Beach County was not hit by Gilbert or Joan. We are one of the fastest growing counties in the nation. Thousands move here every year. 85 to 90% of our population have never experienced a hurricane, but many thousands think they have and that's my problem.

Isadore and Floyd are just two of the weak cyclones that have graced Palm Beach County - named storms, yet not full-forced hurricanes.

It's my experience that when a named storm gets close, be it a dying depression or hurricane, most people react the same: in one of two ways - total panic or who gives a damn. It is then my job to put the storm or hurricane in its proper prospective on radio. It's both harder and easier. While we don't have the advantage of computer graphics to visually illustrate the verbal message and warning, I do have more time to explain what the storm is and what I think it is going to do.

I too, as a talk show host have the advantage of finding out if the message is getting through. I need all the information I can get. Satellite imagery is very important. I learned this in three years working with the old ATS DNG and three satellites at satellite section of the National Hurrican Center in the early 1970's.

But, I know the limitations of even the advanced GOES system. I am able to get the feel for what the storm is doing with the various satellite products, but wait for aircraft data to confirm what I think I see on the GOES imagery.

I have a responsibility to my listener to tell them what I think may or may not happen. We have many thousands of residents on the barrier islands of Palm Beach County, and evaluation will take an estimated 24 to 30 hours. Without the aircraft data, we would probably cry wolf more than we do. This cannot be allowed to happen. When will people stop listening. When it was thought that the reconnaissance aircraft would stop flying and that the current generation of satellites could do the job, I became alarmed and angered knowing that G.O.E.S. alone could not do the job. I too was afraid of the message this would send to my listeners "Hurricanes are no real threat anymore." We don't even need the planes. I feared the public would perceive the real hurricane threat too when the University of Miami football team came to town. At that point, I organized my staff at WPBR radio and we launched a postcard writing campaign to the D.O.T. to save the WC-130 Air Force Hurricane Hunters. I was shocked and quite frankly angered by the response of Air Force officials as I approached them to appear on WPBR to explain their reasons for scrapping the program. One C02 from the Air Force Weather Service told me and I quote "If your listeners in Palm Beach County want protection from hurricanes, tell them all to move to Nevada." This calloused indifference made campaign even more delicate. 30,000 postcards later and with help of my good friend Congress Tom Lewis and many other members of the House and Senate and with wrath of Hurricane Gilbert, Congressman Lewis finally conviced the Transportation Secretary of the Air Force that the planes must remain flying. My job is not any easier, but without Air Force reconnaissance it would have been much harder from a scientific standpoint, but an even harder motivational perspective.

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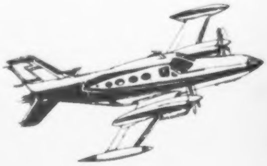

DID YOU KNOW THESE PLANES ARE VITAL IN TRACKING KILLER HURRICANES AS THEY APPROACH YOU?

DID YOU KNOW THE EXPERTS AT THE NATIONAL HURRICANE CENTER SAY SATELITES ALONE CAN'T WARN YOU?

DID YOU KNOW THE GOVERNMENT IS DISCONTINUING THE USE OF AIRPLANES?

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FILL OUT THE POST CARD BELOW, SIGN IT, MAIL IT AND LISTEN TO THE NEW WPBR 1340 A.M. FOR MORE WAYS TO BE HEARD ON THIS VITAL ISSUE!

Mr. LEWIS. Thank you very much.

Mr. HORN. I would like to address just one thing. You were talking about the cavalier broadcaster.

Mr. SCHEUER. I want to know what that means.

Mr. HORN. Right. Well I think what it is—we are in a very competitive business in television, we are all fighting each other for ratings and the advertising dollar and all that. Another problem we have is that we are not all meteorologists. There is a mix of broadcasters and meteorologists working in the weather business, and I think in some cases you get a lot of information in the hands of people who maybe do not have the particular qualifications to necessarily deal with it. So we have that problem too, and we have this mix of professional meteorologists and broadcasters. So in something as diverse as broadcasting with the number of different kinds of individuals working in it, you occasionally are going to get a variance in how the information is put out to the public.

I do not know if you are ever going to totally change that. As professional meteorologists, I think we do our best to comply and be consistent with the Hurricane Center because obviously the worst thing that could happen is that we have got someone saying something, somebody watching Channel 10 which is saying something and is hearing some information and then somebody watching Channel 5 is hearing something else. We do not want people driving into each other, some people leaving, some people staying. But I think as long as we have a free society with independent functioning broadcasting companies, you are always going to have the threat of conflicting information. I think that is something we just have to live with. But that is the way I see it.

Mr. LEWIS. John?

Mr. SCHEUER. Well let me just ask this. Do you mean conflicting information or do you mean conflicting interpretation of the information that the National Hurricane Center is putting out?

Mr. HORN. Yeah, conflicting interpretation and also, as I said, there is always going to be the cavalier broadcaster who will just make his own forecast and present that as opposed to what the Hurricane Center says.

Mr. SCHEUER. I take it these are non-meteorologists.

Mr. HORN. Not necessarily, it could be somebody who was a meteorologist and just does it on their own. I do not know if there are any rules, I do not think there are any written rules as to what someone can say and what someone cannot say. And like I say, and I think Dr. Sheets will back me up, this is not the majority of cases, but it certainly could happen in a storm situation and as he said, did happen on the Texas coast with Gilbert. That is a problem I think that needs to be addressed by broadcasters in the future.

Mr. LEWIS. Mr. Zarella.

Mr. ZARELLA. I was just going to say that on many occasions it is a matter of experience. It is not an intended kind of abuse of power, so to speak. It is a matter where we have an inexperienced reporter. What we try to do is anything that has to do with wind strength, anything that has to do with projected path, track of a storm, et cetera, et cetera, is left up to the National Hurricane Center and what these men are saying on the air. What our reporters in the field can say is gee, that road is closed, this road is closed, this shelter is open—that is the reporter's responsibility because many of the reporters sent to cover a hurricane would not know a gale force wind from a hurricane force wind anyway. They are brought in from all over the country in emergency situations. But a lot of times when you have these errors, it is made simply because you have an inexperienced reporter, which is in fact what happened during Gilbert at the National Hurricane Center, which Dr. Sheets mentioned earlier today.

Mr. LEWIS. Thank you.

Mr. Scheuer, do you have questions?

Mr. SCHEUER. Well I want to say that I have been really tremendously impressed by the awesome amount of knowledge, experience and depth, your gut instincts, that you bring to bear on this whole thing. I think the citizens of America do not have any idea of the professionalism and the vast experience and the training that you folks bring to your jobs. And I stand back in awe of you and I think you guys demand the Man of the Year award and I hope you get it some year, for the marvelous job that you are doing.

I want to ask you to ruminate a little bit about this boy who cries wolf syndrome. How do you do that balancing act? Incidentally I want to ask, why is it that all the hurricanes that sort of peter in and peter out are named Floyd and all the real killer hurricanes seem to be named after women, or a lot of them. [Laughter.]

Has anybody got an explanation for that?

Mr. LEVITT. The luck of the draw. I think Gilbert—I guess Bob Sheets would answer, was named after Gilbert Clark who was probably the most experienced, most memorable hurricane forecaster. He is on Dr. Sheets' staff and I think it is a real disservice that his name was on the list.

Mr. SCHEUER. Let me just define it and then ruminate a bit.

Mr. LEVITT. Sure.

Mr. SCHEUER. We will have a James Joyce here, sort of stream of consciousness.

You get information and you guys say this thing is technically a hurricane but it is sort of petering in, sort of breaking off. Or maybe some of you feel that way. Another of you may feel well who knows where it is going, who knows whether that gale force is really petering out, you know, my God, am I going to decide whether I am not going to give this warning. Maybe we had better tell the folks what we know and let them make a judgment call.

How do you decide whether the risk is real enough to give people the information, perhaps tell them that we cannot make a definitive judgment, that you think they are entitled to know this is what is going on out there, this is not an exact, precise science, the business of defining what is there and saying the exact path that it is taking and how much gale force—additional gale forces are going to pick up. I do not suppose it will ever be a precise, exact science. How do you cover it?

Mr. LEVITT. I do not think so. Congressman, it is very difficult. And with our experience here at the table and what we try and do is we look at all the material, the discussions, the technical discussions that come from the National Hurricane Center, the progs, the probabilities that Dr. Neal Frank spoke about down in Miami this morning, and basically—and I will say this, in the two years that I have been back in Palm Beach County after having worked in New York for a couple of years, we have great one-on-one communication with Dr. Sheets and his staff. And whenever there is any type of a threat to Palm Beach County or south Florida, we call down there and no matter how busy they are, even at the height of Gilbert, Dr. Sheets or a member of his staff will come on and we ask those questions, does it look like it is going to get here, are we going to get a fringe, are we going to get a tropical storm force winds, what is going to happen. And basically what we do is we look at the information, all of the progs, the prognosis that come from the Hurricane Center, and we deal with that. And I guess I am in a little bit different position because I also happen to be a talk show host and I get the immediate response back on open phones. People will say is it going to do this, is it going to do that. If Dr. Sheets puts up warnings, those warnings to out immediately.

And then we get advice from the emergency management here in Palm Beach County and we will broadcast that. If somebody asks me what I think, I will tell them based on my experience. But we will—it is my policy running a radio station, we will never usurp or in any way disagree with the warnings, the watches or the advice that comes from the National Hurricane Center.

John.

Mr. ZARELLA. I was just going to say that, again pretty much to echo what he said, we do not say whether a storm is a big storm, a small storm, what the winds are. It strictly is the forecast from Dr. Sheets or whomever is speaking for the National Hurricane Center in our broadcast. We do not make our own judgment calls, they are the experts, that is what they get paid to do. They make those—and that is why I said in my statement that it is all the more important that they have all the data at their hands to make the right call because a few mile an hour difference in winds can make an incredible difference in the amount of damage that is done.

Just a case in point very briefly, not this past hurricane season but the season before, which is in my written statement, there was a hurricane that was a category three that crossed across—came across the Dominican Republic, almost fell apart. During the course of overnight it suddenly picked up speed, forward speed of about 50 or 60 miles an hour. Never before—it had been unheard of. And it slammed into Bermuda. They would not have known the intensity and the reintensification of that storm if there had not been, just by chance, a hurricane hunter aircraft in that storm at the time. A perfect example of the extreme value of those resources.

Mr. SCHEUER. This is fascinating.

Mr. LEWIS. Mr. Horn.

Mr. HORN. The credibility thing, how do we pull it off. As John was saying earlier, I think a lot of it is experience, there is no substitute for it of course. And what we as broadcasters try to do is present the facts to people as we know them, and I think the experienced broadcaster is able to do that in a manner that exudes credibility. I remember my first few years in television dealing with various weather situations, I did not know the boundaries, did not know how far I should go in terms of showing people how intense a situation I thought there was. Now that I have been in this game for ten years, you know, I have a better sense of any particular storm, how to treat it.

With Gilbert, obviously a very intense storm, very, very nasty, everybody is hearing about it, but the way I handled it was to present it in a manner that it is a storm for these folks, not for us. In that way trying to calm people down. Even though we have a very powerful storm, there is no indication it is going to move in our direction. In other words, just try to state it in plain, every day language, tell people what is happening and let them make their own judgment, because they are going to anyway of course, but we have to present the facts as they are.

Credibility is a hard thing to come by. It is something that you earn and you certainly hope for with time.

Mr. SCHEUER. Well the three of you have sure as hell earned it with me today. Thank you for your marvelous testimony.

Mr. LEWIS. Gentlemen, I would like to ask one general question of the three of you. What changes do you feel in presentation of hurricane reconnaissance data and other data should NOAA be working on to improve both the accuracy and ease of understanding for the general public?

Mr. ZARELLA. Well briefly what we have tried to do is that I believe, and our network feeling is that, if you educate the public to what the dangers are of a hurricane, if you can educate the public, you are much better off than trying scare tactics and panic—got to get out of town now.

What we have done during our live broadcasts from the National Hurricane Center is to pretty much make them a science lesson. We will go on the air—earlier you saw Dr. Sheets up here and he was showing you the slosh models of the inundation of coastline. During some of those live broadcasts that we did last year from the Hurricane Center during Gilbert, we broad those slosh models, which are rather large charts, and put them on the air and explained to the people of the Texas Gulf coast if perchance Gilbert should turn and come your way, this is what you can expect. We were showing tens of thousands of people exactly what they could expect based on science. We did that with Doppler weather radar, cross sections of the hurricane, pictures that were being fed back from the NOAA plane, that showed this unique double eye wall structure that had formed in this storm because of his massive intensity. So we were teaching people.

I think that if you can educate people along the way through technology simply in English language, because we are all laymen—if you can do that, you have a much better chance of getting an educated public out there that will respond when someone says this is a Gilbert, it is not a Floyd, it is time to get out. If they are educated, they will move. The American public is not stupid.

Mr. SCHEUER. Well does that not mean that you have to do this job, you know, month in, week in and week out all around the year, so that this enlightenment process is a systematic, continuing ongoing thing so that when the crisis arises, people have begun to get a feeling for what it is all about and can interpret and act on your recommendations?

Mr. ZARELLA. Absolutely—absolutely. The problem obviously is—we are in a unique position at CNN and we have the time to devote to doing a science lesson. You cannot look at the other networks and expect them, unfortunately, to be able to do that. They just do not have that kind of time, or maybe they do not have the inclination, I am not sure which, but we have the time to devote to doing this kind of reporting. And our problem is, I wish everybody did watch CNN but not everybody does, so we are not hitting all the people. But if you are hitting enough people perhaps the right information is spreading. That is the way we have to look at it.

Mr. Scheuer. Well maybe it is time for the three major networks to sort of review their obligations.

Mr. Lewis. You mean four major networks.

Mr. Zarella. The fourth major network is living up to its obligation.

Mr. Scheuer. Well I meant the other three major networks.

Mr. Zarella. There is in the back a copy of a release, again a little self-serving, but from a newspaper critic in San Francisco talking about the Gilbert experience and addressing exactly what you said, the other networks who used to be the ones that were relied on in times of crisis have fallen off and are not there any more. You may have a copy—there it is there. Again, it is a little self-serving, but I think it states exactly what you are saying.

Mr. Scheuer. Maybe the networks should do some thinking about narrow casting rather than broadcasting. In other words, working with their affiliates in the regions which are really at risk and urging them, maybe giving them some little incentive to do the kind of in-depth, continuous reporting that will educate the public in the coastal regions, perhaps people who live in Kansas and Nebraska do not need it quite so much. It seems to me that the three other networks ought to be thinking about working with their affiliates where there really is a gap and really is a need on an ongoing basis.

Mr. Zarella. That has been the problem, that the networks leave it up to the affiliates to handle that local coverage completely in most cases, and they are just looking at the big picture.

Mr. Scheuer. Well the affiliates ought to be thinking about their big picture. If I was an affiliate in the Gulf coast area or in this area or in the west coast area, I would think that is a major mission for our little station.

Mr. Zarella. One other interesting thing just to point out that has not been brought out today, that during the live broadcasting from the National Hurricane Center, one of the very positive things that is done there is that if a storm is affecting the Gulf coast, the local stations who are at the National Hurricane Center, say from Mobile, Alabama or from Galveston, they get priority over a station from Miami that wants to broadcast live. The priority is in the right place. If the storm is hitting the Gulf coast, those local stations, if they feel like they want to broadcast from the National Hurricane Center and have Dr. Sheets or one of the folks on live, they get first priority, which is certainly along the lines—at least that is being done.

Mr. Lewis. Dr. Sheets, I think you had better get some extra room down there in Miami. I think you are going to have three other networks continually broadcasting after today.

Art?

Mr. **Horn**. I just want to say one brief thing and then I have to go because I am running short of time.

Mr. **Lewis**. You have to do a program.

Mr. **Horn**. One thing I would just like to address on the Hurricane Center is in terms of the question about what can they do to improve the information going out to the users, one thing I would say is to keep in mind—CNN's case is different because you guys are on all the time, but in the case of the affiliates and this is in consideration of the different time zones, keep in mind as to when we go on the air because when we get those statements, if that statement comes to us at 6:00 and we are on by 6:15, it is more difficult for us to relay that information to the public because we do not have much time to visually portray it. If we get that information a little earlier than say 6:00 or 5:30 or whatever, or a little before 11:00 at night, that will help us to put that information not only in words but in pictures, because in television of course that is what we have to deal with, pictures. And sometimes, I know many times, when it is 11:00 and I am trying to redraw something that is going to be on the air, it takes time. In many cases the meteorologist also has to be the graphics artist. And in order to portray this information, we need a little bit of time.

They do a good job at this in most cases, but in other cases sometimes we are a little squeezed. I know it is not a perfect situation, but it would be a help to the broadcasters if the Hurricane Center keeps in mind that we need a little bit of lead time to portray this information in its most useful form.

Mr. **Lewis**. Thank you, Art. John.

Mr. **Scheuer**. Can I ask a question?

Mr. **Lewis**. Yes, sir, any time.

Mr. **Scheuer**. What would it take—you know their problems, what kind of extra effort, what kind of extra technology, what would it take to give you that more lead time?

Mr. **Horn**. Fifteen minutes. You know, if the——

Mr. **Scheuer**. How do they do it, they are nice people, they would do what is reasonable, what is helpful. What do they need to give you that 15 minutes?

Mr. **Horn**. Well more money—no, I do not know. The Hurricane Center has their problems and we have ours. But—and all I can do is try to relate my problems to the Hurricane Center and tell them what my needs are. But as far as what the Hurricane Center needs to be able to give us a little more time, I do not know.

Mr. **Scheuer**. Let us ask Dr. Sheets.

Dr. **Sheets**. We have more money than we know what to do with. [Laughter.]

Mr. **Scheuer**. That would have pleased Congressman Sensenbrenner.

Dr. **Sheets**. No, actually indeed we are well aware of this problem and I do not believe there was one time last year when there was less than 15 minutes in advance of the news times. So we try to get out these products and they are very much tagged toward the news times, as Art has indicated, so that we hit the 6:00 and of course that is 5:00 central time and 11:00 here is 10:00 central time. We always put those out 30 minutes in advance.

One thing that you will be pleased to know is that part of the AWIPS program that you heard about——

Mr. **Scheuer**. Under the jurisdiction of this Subcommittee.

Dr. **Sheets**. That program includes ability to provide graphic materials, and you are exactly right in how you communicate this kind of information to the general public, and one of the problems that we have is that Art will prepare one type of graphics and his competitor down the street will prepare a different type of graphic, and we need a more standardized product. And the AWIPS program is designed to do that. We prepare graphics within the National Weather Service that he can pull up on his computer instantaneously and he could be out on the set, and there it is. So that is part of the AWIPS program and indeed I think that will be a considerable improvement in the ability to communicate through the media.

Mr. **Scheuer**. Great. Well the AWIPS program is the central nervous system really of the whole Weather Service reporting scheme, it ties it altogether, whips it out. We are very, very strong supporters of the AWIPS program, this Committee and this Subcommittee and I am delighted to hear that this may be part of the answer for Art to get that extra 15 minutes he needs.

Dr. **Sheets**. I assume people knew I was joking when I said we had more money than we need. It is on the record, you know, and that is——

Mr. **Lewis**. That is right. Mr. Levitt. Art is going to have to leave. Art, we sincerely appreciate you being here.

Mr. **Levitt**. As I said earlier, in radio we do not have Art's problems. We are able to be more flexible and get the information on. What I think—one thing I will again say while Dr. Sheets is in the room, that the last two years, we at WPBR have had about the finest cooperation with his staff, whenever we needed them, whenever there was a perceived threat to Palm Beach or south Florida, Dr. Sheets would come on live with us, answer questions, or a member of the forecasting staff, and we at WPBR thank Dr. Sheets and his staff for their cooperation.

What we need sometimes, particularly this year when the forecasters are very busy and they have two storms, the scenario that John mentioned when Florence was going into Louisiana and Gilbert was just getting going, what we could use is a little maybe more embellishment in the advisories about the storm, it is going to move west, may move west in another 24 hours or something, just a little more descriptive. There was a time, even when I was a kid, when there was a part of meteorology that was basically descriptive meteorology before we had satellites and everything else, where the meteorologist had to physically describe what a weather map looked like. Being self-serving and being in radio, if the advisories could just be a little more flowery it helps us and I do not mean flowery for flowers sake, but just more descriptive of what is going on, so we can interpret their thinking, number one, and number two, get their message.

But again, I will say from our point of view the last two years, Dr. Sheets and his staff have helped make a big difference for the listeners in Palm Beach County. If I can, Congressman, I will second what John Zarella and Art said, and that is we start in early May with hurricane tips, advising people what the terminology is, they need to know the difference between a depression, a tropical storm, a hurricane and the categories one through five on the Saffir/Simpson scale.

What it is, is ongoing, ongoing education and re-education and again, I think last year's campaign that I worked on with Congressman Lewis, the people in Palm Beach County found out what the reconnaissance aircraft were, we thank Dr. Sheets for coming on many times on WPBR and explaining why he needed the aircraft, what they meant to the people of Palm Beach County, and I think our listeners found out through this postcard writing campaign indeed how valuable the planes are.

We have a job of educating, as John said, we take it very seriously at WPBR. I will say this, what we need is for Dr. Sheets and his staff to have all the tools they need to give us the information so we can motivate people if they have to leave the barrier islands or if they have to leave the Island of Palm Beach. I want to know that Dr. Sheets and the material coming out of the Hurricane Center, he has every piece of information he needs.

Mr. LEWIS. Further questions, Mr. Chairman?

Mr. SCHEUER. No, I just want to say that we are all absolutely determined that he will have all the information he needs and he will have the state-of-the-art technology to get it.

Mr. LEVITT. And 30,000 people in Palm Beach County agree with you and that is why they made a very special effort over four or five months to let Congressman Lewis, to let you and let the Department of Defense know that they need those planes so Dr. Sheets can tell them when it is safe to go back to the water. Thank you.

Mr. LEWIS. Any questions, staff?

[No response.]

Mr. LEWIS. Thank you, gentlemen, we appreciate your input very much.

Mr. LEVITT. Thank you, Congressman Lewis.

Mr. LEWIS. Mr. Chairman, can we take about a three minute break and then come back and have the last panel.

Mr. SCHEUER. Sure. You are the boss.

[Recess.]

Mr. LEWIS. We are going to reconvene the hearing, gentlemen and ladies. I would like to ask Dr. Gray and Dr. Black to please come forward.

First let me thank you gentlemen for taking the time to be here. I know you have had a very busy couple of days, and to take time out and spend them with our hearing is most appreciated. Your testimony, written statement, will be made a matter of the hearing record and if you would take a few minutes to summarize, we would appreciate that. We will start with Dr. Gray.

STATEMENTS OF DR. WILLIAM M. GRAY, COLORADO STATE UNIVERSITY, FORT COLLINS, CO, AND DR. PETER BLACK, METEOROLOGIST, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Dr. GRAY. Thanks for inviting me down here. I am from Colorado and usually mountain states do not make an input.

Mr. LEWIS. Is this not great weather here?

Dr. GRAY. Well it was snowing when I left last Tuesday.

Anyways, I have been quite involved with this recon question since the Air Force made a decision that they would like to drop the recon flights in Guam and then extended to the Atlantic area. I think this has really stimulated a lot of flurry of activity and interest and so on on the reconnaissance question. And in many regards, that is very positive, I think because we have gone on all these years and we have not had enough examination of just how beneficial the aircraft are in an objective way. I think the Air Force action here has stimulated us and in the end, this may be beneficial.

I was Chairman of the AMS Technical Committee on Hurricanes and Tropical Meteorology at the time, in the spring of 1987, when the Air Force announced their decision to drop the reconnaissance, and our technical group formed a small panel that I was chairman of, to study this question further. So for the last couple of years, we have been studying this in a technical sense, and there has been a lot of new research done on it that probably would not have been done if the threat of the planes going had not come up.

We have gone backwards and forwards. The more research is done, the more you realize what a complex issue this is. It is a very complex, involved issue. There is the objective part of it, the data. There is also intangible questions of society and so on. Like, even though the satellite may measure where the storm is very well, how confident are you that that measurement is as accurate as indicated, how much does redundancy play in it, how much does forecaster confidence matter? All of these questions that are sort of technical in nature come up. And it is tough to answer these, because (1) when the aircraft have flown, the satellite interpreters often have used the aircraft to help them interpret the satellite pictures. So it is not a completely—they are not completely independent. Now when the aircraft have not flown, you often, as we say, have not had the ground truth of the aircraft flights there to tell you just how accurate the satellite is. So it is very difficult to sort of objectively evaluate this.

And the more we have done this and looked at it, the more we come to favor the point of view that it is hard to make a good clear case in the average sense. You cannot say well if you did not have aircraft data, you would see—there is so much average error in distance, there is so much intensity error, there is so much error in what the outer wind distributions are. It is hard to put numbers on that, we are struggling for it. It is also hard to put numbers on—given a degradation of information, how that would affect the forecast, 24 to 72 hours into the future. It is very difficult to really nail this down.

However, we do know in individual cases that the aircraft often make very important differences. There are a number of examples that come up where having the aircraft there has altered the forecast, has made it better. And the National Hurricane Center is gathering individual cases there. So really we come to the point of view that perhaps one of the best selling points for the reconnaissance program is the badly forecast, extreme case where the satellite will not do so well and the aircraft will be there and will definitely help out.

So now there are other considerations here. We understand that the typical reconnaissance program costs $20–25 million per year and yet there has been very little data done on the collected—very little research done on the collected reconnaissance data. For instance, the Air Force program, the flights that are made in the Atlantic have been very little researched. In the west Pacific there was no research done on those flights for many, many years. We have since in recent years, on my project, we have started to do some work on this the last three or four years and we have gotten some paper done and we have learned a lot of new things about the tropical storm because we have looked at the already collected reconnaissance data. This has been a neglect of the American tropical storm community that we have not really worked and looked and utilized the already collected data to learn new things about how the flights are made, what they have to offer, new science games that feed back sometimes three, five, eight, ten years downstream.

It would seem like if you are spending $20–25 million a year to make these flights, you would spend some money to research them under the idea that this information would feed back and help in flights later on. For instance, maybe you do not need as many center fix flights. There are times that the reconnaissance is needed for center fix information, there are other times it may not be needed, the satellite is very well able to measure that center, and you want synoptic or surrounding data would help you tell what the full features are that would help in the 24 to 48 hour prediction.

There are a number of aspects to this whole thing and it would seem like we need to establish if you are going to support reconnaissance at the high cost levels, you should have specific research directed to the technical aspects of the reconnaissance question continually going on, because the technology of the satellite is changing, the technology of the aircraft is changing. There are all kind of new ways to perhaps measure from aircraft what is going on.

One of the big things that has recently come up is this remarkable new Gulfstream or G–4 aircraft that might fly. It has a range of 8000 miles or so and can fly at high levels, nearly up to the tropopause, and that this is a small two-engine plane with a crew of two or three people that could fly much less expensively than the four engine planes do. And you might even arrange some leasing mechanism where it could be leased for so many days per year and fly into storms and things.

There are a variety of new things, new concepts, that it would seem like ought to regularly be studied on a routine basis to feed back into the program to help reduce the cost of it or alter it or develop ways where the program could be made a little more efficient.

I feel that the——

Mr. SCHEUER. Excuse me. I wonder if the witness would yield for a moment?

Dr. GRAY. Yes.

Mr. SCHEUER. I wonder whether you, either now or perhaps when you go back to Colorado, could elaborate on that point, what extra research ought to be done now.

Dr. GRAY. All right, the planes have been flying for many years. The military flights have been going on for 40 years. Now the earlier flights, the data was not that good, but the last 10 or 12 years of flights, there is very good observational data there. Some of it is perhaps not as good as other pieces of data, but it ought to be reduced, refined, studied and see what new science games there are in that might feed back to make the reconnaissance—perhaps in the future alter it, perhaps reconnaissance—like if you want to—my suggestion of course is to keep the reconnaissance program going as it presently is, but also at the same time to perform more research on the already collected data sets to see if they do not have new information that could improve the reconnaissance program.

Mr. SCHEUER. Well it would not be new information, it would be old information, but perhaps with a new twist on it. In other words, you are saying we ought to delve a little deeper than we have up to now to see if in that continuous body of data that is useful going back 10 or 12 years, there are not lessons for us.

Dr. GRAY. That is right.

Mr. SCHEUER. There are not things to be learned by analyzing and evaluating what is already sitting there.

Dr. GRAY. Yes, sir.

Mr. SCHEUER. The taxpayers have already paid in terms of aggregating that information.

Dr. GRAY. That is right.

Mr. SCHEUER. Thank you very much.

Mr. LEWIS. Continue.

Dr. GRAY. All right.

There are a lot of things that the aircraft can do that the satellite cannot do, I think. One is the outer wind distribution. Not only can they measure the eyes a little better than the satellite and the radius of max winds, but they can also measure this outer wind distribution that goes out 50 to 200 miles out from the storm center. Often the clouds that the satellite sees obscure the outer wind distribution. That is an important factor for storm surge and for warning people along coasts and things that the planes can do. That is sometimes a factor that is not mentioned so often.

I also advocate that exploratory work go on with the synoptic reconnaissance. What I mean by that is flights in the middle troposphere, 500 millibars or 18,000 feet or so, that would measure the middle levels because those are the steering currents that drive the storm. And to our northeast, if you look on page 10 or 11 of my report, there is this large data void area to the east of us here where storms are in existence where there is only—Bermuda is the only upper air station there is and the weather shifts we have out there, weather shift echo and delta until 1973 are now gone. Also all the middle level prop plane flying that went on in the 1940s, 1950s, 1960s, early 1970s is now pretty well all gone. So you have lost this middle level data now and that is hurting the forecasts.

And there are times that data out in that area may be more beneficial for the storm than the center fix data. And if it can be done by lighter, less expensive planes, that would be all to the good. We should explore reconnaissance techniques such as that.

Now one of the things about—I think Robert Sheets said that the forecasting has only improved a little bit. The data I have from Charles Newman is that forecasting of the track has improved about half a percent per year for the last 30 years. In other words, track prediction is about 15 percent better than it was 30 years ago—that is all, despite all the new satellites coming in. However, that is a bit of a bum rap on the satellites because the middle level reconnaissance has gone down and the weather shifts, two important ones, have left. So the fact is that you got better despite the loss of this middle level data is a positive trend, the satellites have helped some there, other techniques.

So though the improvement has been slow, it perhaps should be looked at in a little bit better light. I say if you do not keep research and the action going on storms, they are going to get worse rather than better. In other words, just to hold things the way they are is often an accomplishment because the conventional sources of data are going and one of the reasons they are going is because the satellite can do everything for you and you do not need this conventional data. That is a debatable point on certain things.

There is also another important reason to keep the reconnaissance going and that is new science games. That is one thing. But then another important thing is calibrating of satellite sensors. How do you know how good these satellite sensors are measuring unless you have the planes in there to document the ground truth. In the west Pacific, now that the Air Force has stopped flying into storms since August of 1987, we have no way to make new forecast techniques—no way to tell how the new satellite, new Japanese satellite systems and the new U.S. satellite systems out in that part of the world are going to be used to improve forecasting. There is no ground truth, you have just got to go with the satellites themselves. Well maybe they have consistent errors in them.

So what we are doing is we are performing research on the data before they dropped the satellite. We are utilizing a lot of the 1982 through 1987 data to develop the techniques.

Now if you dropped the reconnaissance, you would lose a lot of that ground truth to help with the new satellite systems. That is, I think, an important reason to keep recon, or the military aspect of the reconnaissance going because your P-3s cannot do the whole picture probably.

Another aspect I feel that the recon has to be looked at, has been alluded to by Bob Sheets and others, that we have had a downturn in intense activity along the east coast since 1970, a remarkable downturn. The number of intense storms compared—since 1970 in comparison to the 1950s and 1960s is down to 40 percent of the intense storms. That does not include the named storm, the total storm activity is down but not that much. It is the intense storms have gone down and that appears to be related to west African drought conditions. I was going to show some transparencies but I do not guess it is appropriate now.

But if in wind, this Sahel west African drought runs its course, as it likely will. In the past, for 200 years there have been weather records to show that the west African Sahel drought, you can often have 20-30 year periods of wet and dry weather. When this runs its course, like 1988, the rainfall in west Africa was about normal. Well we do not know if that represents a break or not. But when it does, we likely will have more intense storm activity along the southeast U.S. coast and with the increasing populations and property value and so on, it forebodes many problems coming up.

There is also the question I think in considering the reconnaissance question of the intangibles. There are so many intangibles in this it is hard to get ahold of what is—how much does redundancy, how much does forecaster confidence, how much does the general public, if they know—they see these beautiful pictures on satellite, how much better do they feel if they know there is a plane in there too verifying what the satellite shows or getting a direct measurement on the central pressure, max winds, wind distribution, rather than inferring this information in an indirect way from the satellites.

Let us see if I have any more points to make. I guess—well I will close here by saying that I want to emphasize that there be some—that the reconnaissance costs enough money that we ought to form some group of tropical cyclone experts, a standing committee to study just the reconnaissance question, not other questions, just that, of how reconnaissance can be reviewed, perhaps made a little better, perhaps altered, new ideas, new ways come in and that this would not be unreasonable, the cost of such a standing committee would not be unreasonable given the high cost of the reconnaissance program.

[The prepared statement of Dr. Gray follows:]

(retent)

Report of William M. Gray to the

US House Subcommittee on Natural Resources, Agriculture Research and Environment Hearing

Palm Beach, FL

7 April 1989

Department of Atmospheric Science
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ABSTRACT

This paper discusses the author's current views on the issue of Atlantic hurricane reconnaissance. There are a variety of reasons for continuation of the Atlantic aircraft reconnaissance program and perhaps ever to some expansion of this program. An expanded program might include synoptic reconnaissance missions in the environment of the hurricane. Synoptic flights could be accomplished with smaller and less expensive aircraft. Considerations should also be given to some future upper tropospheric flights of the hurricane environment for better hurricane structure and better intensity and motion change forecasting.

There is a need for more research on the broad ranging technical aspects of the aircraft reconnaissance question. Reconnaissance data which have already been collected by the military should be more fully analyzed and studied. It is suggested that a standing committee of tropical cyclone experts be formed to regularly study and make periodic recommendations relative to the aircraft reconnaissance issue as changing satellite and aircraft technology emerge and as new tropical cyclone scientific knowledge gains are made.

1. Background

My tropical cyclone research group at Colorado State University has recently been studying the technical aspects of the aircraft reconnaissance question. I have been chairman of a small American Meteorological Society (AMS) ad hoc panel that is making a special study of the technical needs for aircraft reconnaissance. We have been trying to come to grips with the difficult question of how much degradation would occur in Atlantic Tropical Cyclone (TC) observation-forecasts if the current military reconnaissance flights or their equivalent were discontinued. A preliminary draft of our report has been sent out for review to about 70 of our country's TC experts. We have had about 50 responses which we are now trying to factor into our final document. We hope to have our report out on this topic by this summer.

My remarks today, however, are my own and do not necessarily reflect the views of the other study panel members or of others of my tropical cyclone research colleagues. I appreciate being asked to give input on this important topic.

As I and our study panel get deeper into the reconnaissance question the more we realize what a complex issue this is. There are so many facets of this question. It is very difficult to quantitatively verify the degree of tropical cyclone (TC) observing-forecasting degradation that will result from not having reconnaissance aircraft. This degradation can vary in different storms and in different forecast situations. There are many intangibles to the reconnaissance question. For instance, how does one measure the value of knowledge redundancy and the improved confidence a hurricane forecaster has as to where a hurricane is, how fast it is moving, how intense it is, or what its outer wind distribution are? Although the satellite may well infer this information in a high percent of the cases, there are currently situations where the satellite information can lead to a degradation of such knowledge over what the aircraft can provide. It is impossible to know beforehand, however, when and where such occasional satellite inferred degradations may occur. In critical forecast situations, measurement redundancy by both the aircraft and the satellite is very important. Redundancy of information for coastal response is deemed very important.

There are also complex economic questions which our study group has not dealt with. Because of many intangibles it is nearly impossible to make an objective cost/benefit analysis with regard to the question of having or not having aircraft reconnaissance. There are a whole range of technical and societal issues involved with this topic. The more we studied this question the more we realize that there is no one person, or no one government group that have the needed broad ranging technical and societal expertise to fully understand and synthesize all aspects of this complex subject. For instance, to what extent do the US coastal and Caribbean communities benefit from the confidence in knowing that a reconnaissance aircraft has directly measured or in the future would be available to measure the center of a cyclone, its maximum wind, and central pressure as opposed to having such information indirectly inferred from the sophisticated remote sensing capability of the satellite?

There has unfortunately been insufficient attention paid to the impact of aircraft reconnaissance on TC analysis and forecasting as satellite remote sensing technology has evolved. Having had aircraft reconnaissance for over 40 years, most American TC forecasters and researchers have not felt the need to make quantitative assessments of how beneficial the AF military reconnaissance has been in order to justify its continuance or discontinuance. Research is only now beginning to focus on this important topic.

The main issue to be addressed is the accuracy of current and near-future satellite systems with regard to the specifying of TC position, motion, intensity, and outer wind distribution without the support of aerial reconnaissance. Also, there is a question of the extent to which aircraft wind measurements taken in the environment of the TC contribute to an improvement of TC current and future movement.

Many TC specialists feel that these are yet unresolved questions which need more study. When aircraft data are available, most TC satellite position and intensity estimates have not been made independent of aircraft information. Satellite analysts often use the aircraft data to assist them in their satellite interpretation. Where reconnaissance flights were not made, ground truth information as to the true accuracy of the satellite estimates are typically not available. There has been considerable and understandable debate between satellite TC specialists and TC operational forecasters in recent years over the detailed accuracy and reliability of these aircraft-independent satellite TC estimates. It is important that more technical studies be conducted to better rectify these differences of opinion.

2. Discussion

This section discusses the author's views on a number of the broad ranging aspects of the reconnaissance question. Details on the technical comparisons of the satellite vs. aircraft measurements of TC position, movement, intensity, and outer wind distribution are too involved to be properly summarized in this report. Appendix A lists recent studies (and a few older ones) that have been directed towards a better technical understanding of this subject.

The author has studied all of the reports in Appendix A. I am of the opinion that there are limits as to how accurately the satellite can consistently and with confidence estimate the position, intensity, and horizontal wind distribution of some tropical cyclones in comparison with what the aircraft is able to do.

This judgement in no way intends to denigrate the invaluable observations of the TC that the satellite currently provides and has provided for the last 25 years. Although the satellite is well recognized as the most important tool for observing and forecasting TCs, this does not mean that the aircraft measurements do not have certain advantages over the satellite in many situations. The aircraft could never replace the satellite as a TC observational tool. This does not mean that the satellite is presently capable of fully replacing the aircraft for the most skillful forecasting of tropical cyclones with potential influences to the US or Caribbean Basin coastlines.

I believe that if aircraft reconnaissance were used to the optimum, with both intensive center-fix and synoptic flight missions, average TC track intensity and outer wind forecast errors would be significantly reduced over the average of forecasts made without the benefit of flights. But this does not mean that measurement and forecast improvements would always occur when aircraft missions were made. There are a high percentage of forecast situations where aircraft data is largely redundant and a smaller number of other situations where it offers significant improvement and forecast confidence over what would be possible from the satellite alone. It is very difficult to put precise numbers on this degree of improvement however. And, it is impossible to know beforehand in which cases the aircraft will add improvement.

Although average forecast error reduction is an ever present goal, it must be pointed out that it is the contribution to the reduction of the few worst observation-forecast errors for which aircraft reconnaissance is most important. This is the aircraft's highest selling point. It is the occasional badly observed TC for which the largest potential forecast and warning problems reside. Space does not permit the documentation of individual cases of large TC track and intensity forecast errors which would likely have occurred in certain forecast situations if aircraft reconnaissance flights had not been made. The National Hurricane Center has started to assemble a list of such special cases.

The Hurricane's Outer Wind Distribution. In addition to the aircraft's ability to directly measure the TC's inner-core wind distribution, the aircraft can also directly measure and/or well infer the TC's outer radius (1-3°) wind distribution which the satellite is currently incapable of doing. Forecasts of the TC's outer radius wind distribution is required for shipping interests and in specifying the radial extent of damaging winds. The TCs cloud shield typically prevents the satellite from observing outer-core (100-300 km radius) wind speeds.

The author's project recent research (Weatherford and Gray, 1988a, 1988b) has shown that the strength of the TC's outer 100-300 km radius low-level wind circulation and its changes with time are often very little related to the TC's minimum central pressure and its changes. Satellite techniques for estimating a TC's maximum intensity does not ensure a reliable specification of the TC's outer-radius wind distribution. It is observed that some intense TCs have weak outer-core wind strengths while other TC's with much stronger outer circulations may have only a moderate or weak maximum wind speed.

Procedures for accurately specifying the radial distribution of winds from a satellite have yet to be devised. When and if such procedures are devised they would not be expected to be as accurate as the direct measurement of this wind distribution from an aircraft.

The new developments of satellite microwave imagery (SSM/I) show much promise in helping to specify a TC's far removed (radius > 3°) surface wind distribution. This instrument was first flown last year on a DMSP satellite and will be part of the instrument package of future DMSP satellites. The SSM/I sensor cannot measure winds above 15-20 m s^{-1} however. It attenuates in heavy rain situations, and has yet to be thoroughly tested in a variety of different TC operational conditions. Although SSM/I imagery will likely offer important future assistance in specifying a TC's further removed (radius > 300 km) surface wind speeds, it will likely offer little assistance in the next few years at the specification of the TC's inner 100-300 km radius wind speed profile. At the present time only aircraft reconnaissance can provide a reliable measurement of this feature.

Synoptic Track Reconnaissance. Synoptic reconnaissance 1000-500 km on the north and northwest sides of the TC will almost always improve the assessment of the TC's synoptic environment. This can often lead to improvements in the 1-3 day track forecasts - see attached article by Shoemaker (1988). The area of the Atlantic southeast of the US coast is devoid of conventional rawinsonde information except for Burmuda (see Fig. 1). Many TCs in this open water region influence the US. Middle tropospheric wind information in this data void region are very important for improved predictions of where a TC located in this region will move. Compare tracks a and b of Fig. 2. Middle tropospheric (~ 5 km) wind and pressure-height information in the shaded region of Fig. 2 would greatly assist in the forecasting of right turn vs. straight motion. Satellite technology is presently incapable of making accurate middle troposphere wind and height measurements.

Please note that synoptic track missions are not required to fly near the TC center. It would be beneficial if the US government give consideration to the making of these types of synoptic flights (in situations where they would be helpful) in addition to the type of center fix reconnaissance currently being considered. There are situations where synoptic flight missions would be more desirable than center-fix missions. Improvements in statistical and numerical model TC track predictions for the longer 1-5 day time periods could be obtained

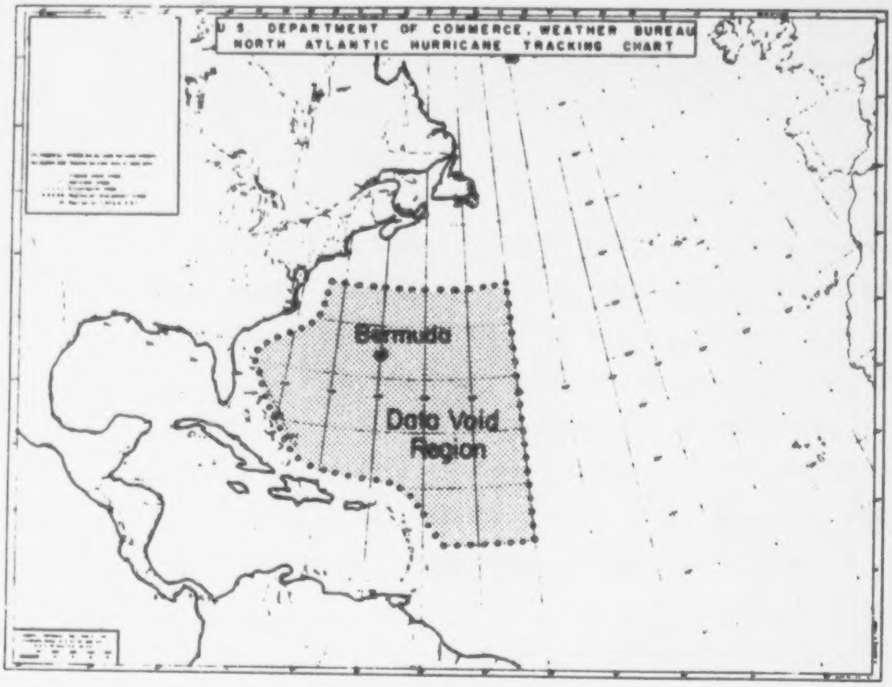
U.S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
NORTH ATLANTIC HURRICANE TRACKING CHART
Bermuda
Data Void Region

Fig. 1. Portrayal of Atlantic conventional upper-air data void region. Bermuda is the only upper-air station over a broad region of the Atlantic where the knowledge of wind information around the TC is so important.

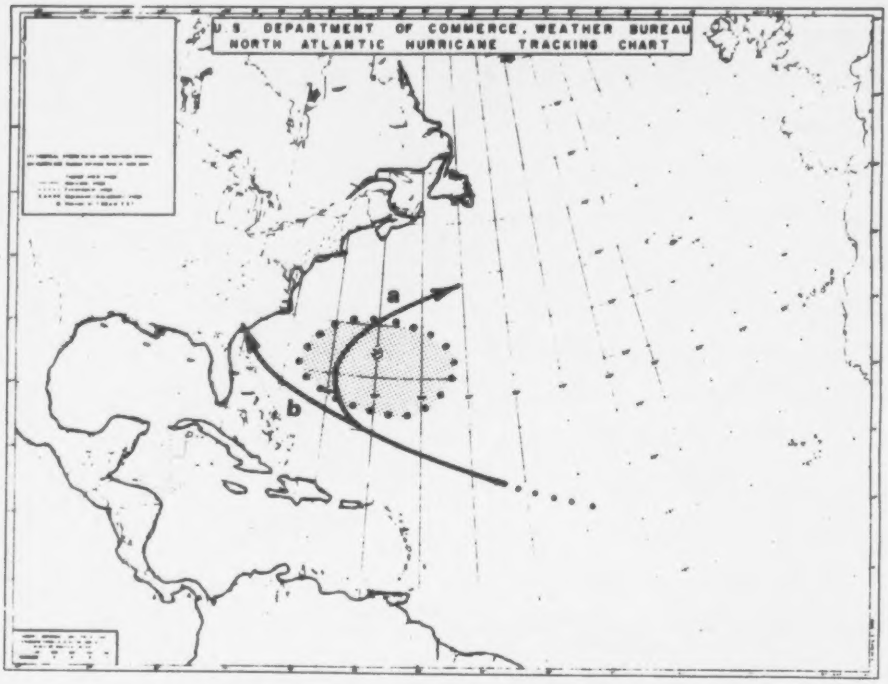
U.S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
NORTH ATLANTIC HURRICANE TRACKING CHART
a
b

Fig. 2. Idealized portrayal of two hurricanes tracking WNW but one storm turns to the right and recurves (track a) which the other storm (curve b) continues on its WNW track and makes landfall on the US coast. Data in shaded area would offer much assistance in the forecasting of such track differentiation.

if the data void regions surrounding Atlantic tropical cyclones could be sampled at middle tropospheric levels.

New Sensor Systems. Are there not new sensors coming on line which will soon eliminate or greatly reduce the need for TC reconnaissance however? A compilation of expected new remote sensors is shown in Table 1. This table also indicates the time frame of when the initial operational capability is expected, and when the final operational capability may be anticipated. By the time of Final Operational Capability (FOC), it is expected that the necessary algorithms, techniques, software, and operational testing will have been completed.

Although these new satellite, radar, and other sensor technology advances appear to hold much promise for TC observation-forecast improvements, these new advances have yet to be thoroughly tested in an operational environment and shown to be of comparable value to the information that reconnaissance aircraft can provide. The prospects for significant improvement in new sensor systems in the next few years will likely not be sufficient so as to relieve the requirement for aircraft reconnaissance - particularly along the hurricane vulnerable US and Caribbean Basin coastlines.

Although improvements are being made in operational utilization of satellite data for TC observation, there is a limit to the extent that new remote sensor refinements and new satellite processing, display, and interpretation techniques can be carried without more basic satellite sensor improvements. Such basic sensor improvements appear to be (at least to this author) a number of years off.

TABLE 1

New remote sensor technology expected for operational use in the near future. IOC means initial operational capability; FOC means final operational capability.

Name	IOC	FOC
Special DMSP Sensor Microwave Imager (SSM/I)	Validation	1990 (2-satellite suite)
Mini Drifting Ocean Buoys	Final Engineering Testing	Spring 1990 (one year operational evaluation)
GOES-NEXT	Summer 1990	1992 (2-satellite suite)
Next Generation Weather Radar	Fall 1990	1994 (mainland U.S.) 1994 + (Hawaii and Caribbean)

While emerging improvements in operational satellite sensor and in landbased radar technology in the next few years may lead to some reduction in the need for center-fix aircraft reconnaissance, it is likely that these technology improvements will not be sufficient as to alter the current need of aircraft reconnaissance for US and Caribbean Basin coastal warnings at least not for the next few years. New technical advances often take several years to be fully tested and accepted for operational utility.

Typical lengths of TC warning zones along the US coast average 556 km (300 n mi). Inasmuch as the average width of the hurricane damage swath is typically about 185 km, nearly two-thirds of the warning zone represents over-warning. It is likely that the increased uncertainty through loss of aircraft reconnaissance, actual or perceived, would lead to even greater over-warning and thus additional loss of credibility. Warning credibility is an important issue.

It appears that those individuals (with quite laudable concerns for the high costs of TC reconnaissance) with the greatest confidence as to the technical feasibility of the satellite and other remote sensor systems being able to perform the full TC observing task without reconnaissance aircraft, are typically individuals who have not had the responsibility for making TC forecasts. Most of those TC forecasters who have had such responsibility and have made many TC forecasts in situations where aircraft reconnaissance information has and has not been available are firm in their views that superior and/or more confident TC forecasts can usually be made when reconnaissance information is available as to those situations when it is not.

Aircraft Technology Improvements. As satellite and land based sensor improvements occur, so also, will technical improvements likely be taking place in aircraft reconnaissance. There have been and are currently important new improvements in aircraft navigation, doppler-radar wind measurement, aircraft communications, and many other new and expected future developments. In an evaluation of the reconnaissance issue, it is important that forthcoming improvements in aircraft reconnaissance technology be given equal consideration with the expected technical advances in satellite and radar technology. For instance, the new Global Positioning System (GPS) due for implementation in the next couple of years is expected to allow an aircraft to position itself to an accuracy of less than a few hundred meters. The recent development of higher altitude aircraft with longer-range and INS navigation will allow for longer-range and faster synoptic track reconnaissance at a much lower cost than currently is possible with the larger 4-engine C-

130 and P-3 aircraft. The new Gulfstream (G-4) aircraft has a range of 8000 km and can fly at levels up to the tropopause (~ 15 km). The possibility of TC upper tropospheric reconnaissance with an aircraft of this or other similar type would lead to improvements in observing and predicting TC structure, intensity change, and motion. In that the number of such flights would be seasonally limited some sort of government leasing mechanism might be arranged for the 10-20 days per year when such flights would be desired. Specialized aircraft instrumentation might not be required.

New research studies are showing the importance of knowledge of a TC's environmental wind information to its future motion track. Knowledge of a TC's upper tropospheric surrounding winds are very important for the forecasting of future TC intensity and motion change for calibration of new satellite sensors, and for new TC basic science gains. It is sad that the only upper-tropospheric reconnaissance and research flights into hurricanes were made in the middle 1950s to the late-1960s period and none since. There are unique features of the TC's upper troposphere which only an aircraft can sample.

US Southeast Coastline as a Special Basin Needing Reconnaissance. The need for aircraft reconnaissance in the Atlantic is quite different from that of the NW Pacific. Judgments as to the needs and benefits of center fix or synoptic aircraft reconnaissance do not necessarily carry over from one ocean basin to another. The potential economic impacts on US interests in the NW Pacific (where aircraft reconnaissance has recently been discontinued) are quite minimal in comparison to US economic interests in the Atlantic basin. The storm surge problem in the NW Pacific (for US interests) is quite minimal in comparison with the potential major storm surge problem along the US coastline.

Long Period TC Track Forecast Improvements. Neumann (1988 - Appendix B) has shown that Atlantic TC track forecast skill improvement over the last 30 years has only averaged about one-half percent per year or roughly 15%. This is a quite modest improvement, particularly when one considers the large technical advancements in satellite technology over this period. Such technical advances in satellite technology have manifested themselves very little with respect to TC track forecast improvements.

The discontinuance of aircraft reconnaissance in the Atlantic would likely set Atlantic TC forecast skill back to levels similar to those of the track forecast skill capability of the pre-satellite era. It is noted that strategically positioned Atlantic weather ships and Atlantic middle-level prop aircraft flights which provided much middle tropospheric wind-height information (crucial for TC steering flow determination and motion forecasting) in the 1940s, 1950s, 1960s, and early 1970s have now almost entirely disappeared. This is one of the reasons why TC track forecast skill improvement has not been greater.

New Science Gains and New Sensor Calibration. Information from operational reconnaissance (if utilized) is also a valuable source to supplement new science gains on the physics and behavior of tropical cyclones so that improved future forecast techniques can be developed.

Reconnaissance is also highly desired to document the validity of the new satellite, radar, and other observing sensors that will be coming on line in the future. How is ground truth as to the accuracy of these systems to be established? The aircraft is the most effective source of this validation. The NOAA research aircraft capability of two P-3 aircraft is presently insufficient for such full sensor documentation in the Atlantic. There is presently no comparable way to validate new satellite sensors in the Pacific where the largest number of tropical cyclones occur.

Loss of science gains and loss of ability to calibrate new satellite and radar sensors are other important factors that should be given consideration before decisions are made on the desirability of retaining or discontinuing reconnaissance. For instance, the author's research project is presently attempting to develop improved satellite based TC forecast techniques in the Northwest Pacific where aircraft reconnaissance was discontinued in 1987. It is impossible to develop such techniques based on the satellite information alone. We must thus concentrate our research on the period prior to 1987 when reconnaissance aircraft were available to give "ground truth" calibration to the satellite products. In the Pacific we have thus lost our ability to develop new objective satellite-only based TC forecast techniques with future satellite products. One would never know without direct aircraft measurements just how accurate any such satellite-only forecast technique would be.

Possibilities for Increased Atlantic Hurricane Activity in Coming Years. There has been a notable decrease in Atlantic severe hurricanes in the 1970s and 1980s in comparison with the intensity of hurricanes of the 1950s and 1960s. For instance, there were 69 hurricanes with sustained maximum wind equal or greater than 100 knots (115 mph) during the 1950s and 1960s but only 31 such hurricanes during 1970-88. This represents an annual ratio difference of greater than two to one in favor of the earlier period. The less severe hurricane period since 1970 (except for 1988) is well associated with the extended period of west African summer drought conditions which have prevailed since 1970. The most intense hurricanes usually form at low latitudes from disturbances propagating westward from Africa.

The coastal populations of the US and Caribbean Basin have been fortunate that intense hurricane activity has been so low since 1970. It is impossible to tell how long this downturn of intense hurricane activity and destruction potential will continue. It is to be expected that a return to more intense hurricane activity will occur when the atmosphere's global wind systems experience a change in their multi-decadal circulation patterns and West Africa again experiences more summer rainfall. Such multi-decadal circulation changes have occurred many times in the past. It is impossible to know whether 1988 represents a break in this recent multi-decadal period of reduced TC activity. (See pages 14-25 of Appendix E for more information.)

With the large increases of US coastal populations and building construction which has taken place since 1970 and will likely continue to occur in the future, it is likely the US will have many more future hurricane problems in the next decade or two than we have had in the recent past.

Political-Societal Considerations. The political consequences of a not-very-accurate TC forecast that produced substantial amounts of US coastal damage or loss of life and in which reconnaissance aircraft were not flown would likely be enormous regardless of whether or not such reconnaissance information would have had an effect on the forecast.

3. Recommendations

The author recommends that:

1) the present Atlantic reconnaissance program be continued irrespective of whether the Air Force or some other US government agency does the flying. The new IWAR instrumentation being installed on the C-130 aircraft has already been committed. This new instrumentation will offer new possibilities for improved aircraft reconnaissance if a continuous monitoring and updating of the reconnaissance procedures are accomplished.

As aircraft instrumentation advances and as our general knowledge of how to more effectively utilize aircraft reconnaissance increases, it is likely that the general value of the aircraft for TC observing-forecasting will likely be found to be higher than it has been in the recent past. It is possible that future technical advances in aircraft reconnaissance may be as large or larger than the current and expected technical advances occurring in the satellite field. This is particularly the case if new and innovative measurement procedures and flight tracks are more intensively researched and widely discussed within the broader US tropical cyclone community.

2) It is likely that beneficial improvements in reconnaissance flight techniques and some cost savings may be possible if more direct research on the reconnaissance topic is made. Judgement of the TC aircraft reconnaissance program should not be made only on the basis of past utilization and assumed past benefits but on the basis of the likely new developments in aircraft and satellite technology. Consideration should also be given to the question of whether the

aircraft reconnaissance has been or will be utilized to its highest potential. This may not always have been the case with regards to the aircraft reconnaissance program in the Northwest Pacific prior to 1987. Little research was accomplished on the NW Pacific reconnaissance data prior to the middle 1980s in order to help optimize future flight planning, forecast improvement, and new science gains. This was unfortunate. Research costs on already collected data aircraft sets are a pitance compared to the expense of making such flights. Had such research on the already collected NW Pacific reconnaissance flight data been made it is likely that a higher return would have been received from such flights.

It would be desirable if more efforts were made to analyze the already collected military tropical cyclone reconnaissance missions in the Atlantic and Pacific.

3) It would be desirable if a standing committee of tropical cyclone experts be formed to more fully study the aircraft reconnaissance question in its broadest aspects. This committee might periodically make recommendations for alteration or additions-reductions in Atlantic reconnaissance procedures, flight tracking, etc. as new technology and new TC science gains are made. Such a group should include university and private industry specialists as well as NOAA, military, and other government specialists.

Technical questions such as to desired measurement goals, flight tracks, availability of new instrumentation, etc. should likely be discussed in open forum and not just within government circles. This would allow a mechanism for the more efficient input of new ideas and research findings on the reconnaissance topic. It might also stimulate researchers outside the government to make more contributions to this evolving measurement topic.

Acknowledgement. The author has profited from extensive recent discussions on this topic with Charles Neumann, Charles Guard, Ted Tsui and current and former CSU project members Ray Zehr, Daniel Shoemaker, Joel Martin, Robert Merrill, Roger Edson and many other members of the US tropical cyclone community. These individuals may not necessary subscript to some of the views here expressed however.

APPENDIX A

Special Studies Directly Related to the Aircraft Reconnaissance Question. Most of these Studies Have Recently Been Accomplished.

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APPENDIX C

About the Author

The author of this report is a Professor of Atmospheric Science at Colorado State University. He has been performing research on hurricanes for over 30 years. He had his first flight into a hurricane in 1958. Hurricanes were the subject matter of his MS and Ph.D. theses. He has had many graduate students who have specialized in tropical cyclone research. The author has visited the National Hurricane Center for many years and has closely followed the forecast and research activities of this center.

APPENDIX D

Influence of Synoptic Track Aircraft Reconnaissance on JTWC Tropical Cyclone Track Forecast Errors

by

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October 1988

Abstract

This report analyzes the impact on tropical cyclone track forecasting of U.S. Air Force synoptic aircraft reconnaissance. Information on 63 tropical cyclone synoptic track flights into the Western North Pacific during the seasons of 1983-1986 is studied. Analyses are made of approximately 200 Joint Typhoon Warning Center (JTWC) 24, 48, and 72 hour track forecast errors in the 6, 12, 18, and 24 hour period following the synoptic tracks. These tropical cyclone track errors are then compared with the forecast track errors of non-synoptic reconnaissance forecasts. It is found that synoptic reconnaissance distinctly improved JTWC track forecasts.

1. Introduction

Synoptic Tracks were flown by Air Force Weather Reconnaissance aircraft to provide data to Joint Typhoon Warning Center (JTWC) forecasters. These flights were tasked when JTWC believed an ambiguous or difficult forecast situation arose such as whether a tropical cyclone would recurve or not. Synoptic flights were typically flown approximately 5° to 10° latitude north of the storm center, near the subtropical ridge. Tracks were generally flown in an east-west direction at 400mb (approximately 23570 feet pressure altitude) but could include a leg inclined southward ahead of the storm track. Observations were taken at regular intervals (every 60 nautical miles in 1986) and include:

Flight Level Temperature.

Flight Level Dew point.

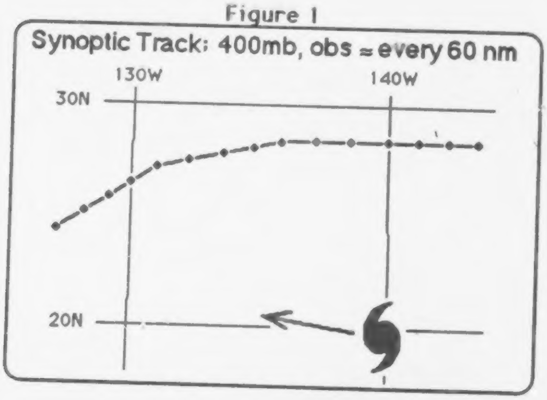
Flight Level Spot Winds.

Flight Level Height of Standard Surface.

Clouds, Weather, and Atmospheric Phenomena near aircraft.

Dropsonde temperature and moisture profiles at selected points including sea level pressure.

Figure 1



Data was relayed to JTWC where forecasters analyzed it in conjunction with other synoptic and storm data. It was also sent by teletype into the Automated Weather network and included in various models and analyses. Winds and pressures gave an indication of the strength of the subtropical ridge and penetration of mid-latitude troughs into the subtropics. A weakness or a trough was a possible sign of recurvature and forecasts would be adjusted accordingly.

Until now there has been no quantitative measurement of the effect of Synoptic Tracks flown by aircraft on JTWC Northwest Pacific forecast errors. Weather reconnaissance has since been phased out in the area, but reconnaissance questions still need to be addressed for other basins. This study was conducted to provide quantitative information and statistics for a position paper on the aircraft reconnaissance question being written for the American Meteorological Society by an ad hoc committee of which Professor William M. Gray of CSU is chairman.

An attempt is made to determine if tropical cyclone forecast position errors for 24, 48, and 72 hours were improved when synoptic tracks were flown. To do so all JTWC track forecasts made 6, 12, 18, and 24 hours after the synoptic track were analyzed for errors. These errors were then compared to forecasts not within 24 hours of a synoptic track. Synoptic track times were taken directly from the Air Weather Service Form 35's used in flight by the Aerial Reconnaissance Weather Officer (ARWO). Verification of forecast errors comes from the Annual Tropical Cyclone Report published by JTWC for the years 1970-1987 and also from a study by Jerry D. Jerrell et. al. (MWR, Jul 78) in which data from 1966-1975 was used to compute average forecast errors for 24, 48, and 72 hours. Jarrell's study also included a latitude and longitude stratification necessary to determine if forecast errors were dependent on these factors. This study encompasses the years 1983-1986 inclusive for which 63 synoptic tracks were available. Inspection of the storm tracks that the synoptic missions supported shows that they were typically made in an equally difficult or in a more difficult synoptic situation than that of the average forecast.

2. Results

Track forecast comparisons are made in Table 1. For the 24 hour forecasts, JTWC's average error for 1983-1986 was 118 nautical miles (nm). If there was a synoptic track within 24 hours of the forecast that error went down to 108nm. The average error without synoptic tracks was 120nm. This is a ten percent reduction in error based on 245 forecasts with synoptic tracks and 1716 1983-1986 forecasts without prior synoptic reconnaissance information.

For 48 hour forecasts, JTWC errors averaged 247nm overall; with synoptic tracks the average error was 209nm; and average errors were 253nm without synoptic tracks. Again, an error reduction of 17 percent based on 229 forecasts with synoptic tracks and 1291 forecasts without.

At 72 hours, the JTWC average forecast error for 1983-1986 was 381nm, and with synoptic tracks it was 318nm. Without synoptic tracks the average error was 395nm. This reduction based on 196 forecasts with synoptic tracks and 924 without, is equal to 19.5 percent--a significant improvement.

Table 1
Synoptic Track Influence on Fcst Errors
Number of Forecasts in Parentheses

1983-1986	24 Hr Fcst	48 Hr Fcst	72 Hr Fcst
With Syn Trks	108 (245)	209 (229)	318 (196)
W/O Syn Trks	120 (1716)	253 (1291)	395 (924)
All Forecasts	118 (1961)	246 (1520)	381 (1120)
Improvement with vs w/o	10.0%	17.4%	19.5%

Errors in Nautical Miles

Is this reduction attributable to the fact that the storms in this study were done at lower latitudes and/or more westerly longitudes where forecast errors are known to be smaller? Jarrell et. al.'s stratifications are used in order to normalize for latitude-longitude changes in forecast difficulty. First, to determine if Jarrell's error distances are still valid, his 1966-1975 results are compared to 1976-1987 and 1983-1986 forecast errors. Table 2 shows that there has been no significant improvement or deterioration of forecast skill with time. Jarrell's forecast error data remains valid today.

Table 2

JTWC Forecast Errors

Years	24 Hr Fcst	48 Hr Fcst	72 Hr Fcst
1966-1975	126	247	369
1976-1987	121	241	364
1983-1986	118	246	381

Errors in Nautical Miles

Jarrell et. al.'s latitude and longitude stratifications are now compared with synoptic track forecasts showing that synoptic tracks weren't flown only on storms where the average error is lower, and that there is an overall reduction in forecast error regardless of latitude or longitude. Figures 2 through 5 illustrate the 48 and 72 hour forecast errors stratified by latitude and longitude.

Figure 2

Latitude Comparison of Forecast Errors

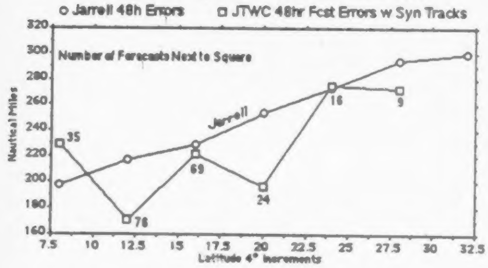


Figure 3

Longitude Comparison of Forecast Errors

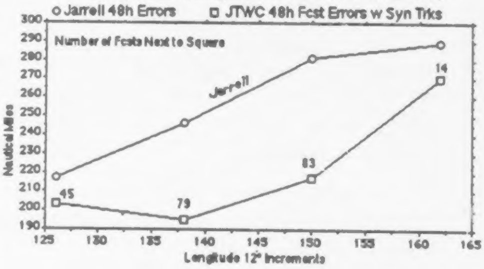


Figure 4

Latitude Comparison of Forecast Errors

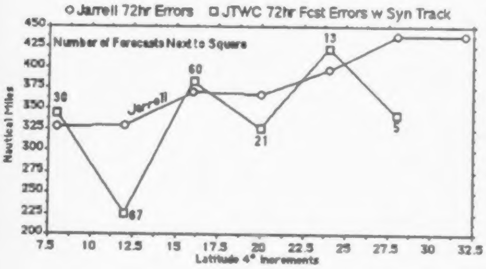
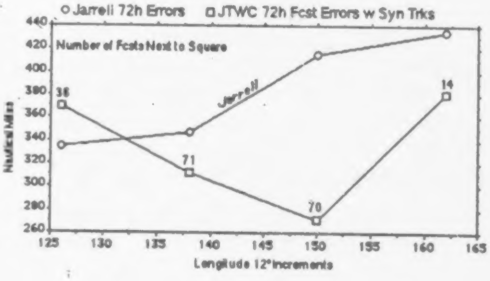


Figure 5

Longitude Comparison of Forecast Errors



Jarrell et. al. unfortunately didn't stratify by both latitude and longitude, which would have created a grid of expected forecast errors by storm position. Then forecast errors with synoptic tracks could have been compared to expected average errors by storm position in a latitude-longitude grid.

Were these easier storms to forecast? The data set of storm tracks for those storms that had synoptic tracks shows eight straight runners, 16 recurvers, and six others (including two storms undergoing binary interaction with other storms). These are representative storm tracks and not an "easy" sample to forecast. A comparison of track forecast errors of two forecast aids attests to the difficulty of the tracks. These aids, Climatology and Persistence (CLIPER), which also includes current intensity and past movement; and Half Persistence and Climatology (HPAC), forecast a storm track, and should do well when a storm forecast is following climatology and persistence. When these aids do more poorly, the storm is following a path not anticipated by climatology or persistence, and is construed to be a more difficult forecast. Table 3 summarizes the forecast errors for these two aids.

Storm track errors were actually higher for storms where synoptic tracks were flown, indicating that these cases were indeed harder forecast situations.

Table 3
CLIPER & HPAC Fcst Error Statistics

	Avg Err 83-86			Avg Err w Syn Trk		
	24h	48h	72h	24h	48h	72h
CLIPER	124	258	391	129	291	426
HPAC	123	245	350	119	267	378
Avg	123	251	370	124	279	402

Errors in Nautical Miles

% Fcst Error Difficulty Incr. for Fcsts w Syn Trk

	24h	48h	72h
CLIPER	4%	13%	9%
HPAC	-3%	9%	8%
Avg	0.5%	11%	8.5%

Another indication of the degree of improved JTWC track forecasting with synoptic tracks is the percentage improvement over CLIPER and HPAC. The percentage of JTWC improvement over the aids increases by approximately 30% at 48 and 72 hours (Table 4) when there was a synoptic track flown within 24 hours of the forecast. . This indicates that JTWC had more skill at forecasting a storm track different from the aids when there was a synoptic track flown.

Table 4
JTWC % Error Improvement over Fcst Aids

	All Fcsts 83-86			Fcsts w Syn Track		
	24h	48h	72h	24h	48h	72h
CLIPER	4%	5%	3%	19%	39%	34%
HPAC	3%	0%	-8%	10%	28%	19%
Avg	4%	2%	-3%	15%	33%	26%

Positive Number Indicates JTWC beat the Forecast Aid

How would synoptic tracks improve forecasting? In the 1985 Annual Tropical Cyclone Report published by JTWC a discussion of Tropical Storm Ellis is presented.

Synoptic track data indicated that the Numerical Variational Analysis (NVA) was misanalyzed and the forecast was adjusted. The NVA depicted weak ridging at 400mb northwest of Ellis and therefore a continued west-northwest track under the ridge was forecast. A synoptic track was tasked due to the uncertainty of these analyses, and data from the track showed northerly flow to the northwest of Ellis. The storm began a turn to the south-southwest and began weakening in response to unfavorable northerly flow. The following day's NVA changed significantly, reflecting the northerly flow found by the synoptic track. Without a synoptic track, the west-northwest storm track would probably have been forecast until the next NVA became available. Forecast errors would have been large because the storm began a turn to the south-southwest during that time.

Sheets (1988) shows that increased aircraft center fixes decrease the number of large errors in short term forecasts. Do synoptic tracks decrease the large errors in longer range forecasts? Errors were called large if they were ≥ 200nm for the 24hour forecasts, ≥ 400nm for 48hour forecasts, and ≥ 600nm for 72hour forecasts. There is a 31, 45, and 17 percent reduction in large errors in the 24, 48, and 72 hour forecasts with synoptic tracks. Although this data sample is not very large, these reductions were obtained on more difficult forecast situations.

Table 5
JTWC Large Forecast Errors

	Percentage of Forecasts ≥		
	200nm (24h)	400nm (48h)	600nm (72h)
With Syn Trks	9.8%	10.5%	14.1%
W / O Syn Trks	12.8%	15.3%	16.6%

3. Summary.

Forecast skill at JTWC hasn't improved appreciably in the last ten years, and large error averages still occur at the 48 and 72 hour forecasts. Martin (1988) showed that long term forecast errors in the West Pacific didn't improve much with center-fix aircraft reconnaissance. If one looks at the effects synoptic tracks, the results are different. When JTWC had a synoptic track flown within the previous 24 hours, 24 hour average track forecast error decreased by 10.0 percent, 48 hour average track forecast error decreased by 17.4 percent and 72 hour average track forecast error decreased by 19.5 percent. The percentage reduction of the large forecast errors was larger than (at 24 and 48 hours) or equal to (at 72 hours) the mean reduction for the mean forecast errors. This was a substantial error reduction, and the loss of aircraft reconnaissance will reduce the potential for an improvement in long range forecast errors which the availability of synoptic track reconnaissance missions afforded.

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NOTE

The author was a former 54th Weather Reconnaissance Squadron (USAF) Aerial Reconnaissance Weather Officer assigned to Guam during the 1985-1986 typhoon seasons. He flew approximately 100 Northwest Pacific storm missions during this time.

ACKNOWLEDGEMENTS

This study was undertaken at the suggestion of Professor William M. Gray. Many thanks for his encouragement and involvement. Dr. Ted Tsui of the Naval Environmental Prediction Research Facility provided the statistics on forecast aid performance. The author is indebted to the United States Air Force for funding his graduate studies at Colorado State University.

Mr. Lewis. Thank you, Dr. Gray. I forgot to say this for the record, but Dr. William Gray is the Director of the Tropical Cyclone Research Group at the Department of Atmospheric Sciences at Colorado State University.

Dr. Peter Black is a meteorologist, Hurricane Research and Development, National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory. Dr. Black.

Dr. Black. Thank you, Mr. Chairman. Half our difficulty sometimes is pronouncing our organizational affiliation.

As you mentioned, my name is Peter Black, I am a research meteorologist with the Hurricane Research Division where I have worked for the past 23 years. I have logged somewhat over 1000 flight hours in various research aircraft doing hurricane research, made over 200 hurricane eye penetrations in these aircraft and flown in approximately 50 different storms.

I appreciate the opportunity to discuss the hurricane forecasting and surveillance program with you. The Hurricane Research Division where I work studies hurricanes through observational and theoretical studies and computer simulation.

Precise estimation of surface winds associated with a hurricane, of course as you know, is necessary for the issuance of warnings by the National Weather Service National Hurricane Center. This requires an accurate knowledge of the storm track and intensity which, in turn, requires an accurate knowledge of the storm's initial position and especially, as Dr. Gray mentioned, the surface wind distribution prior to the forecast time.

If I could just summarize, in the United States today, the tools available for hurricane position estimation would be the following:

The geostationary satellite system, both visible and infrared sensors; polar orbiting satellites, visible, infrared and microwave sensors, which have been discussed today; radar, both land based, airborne and I might add skywave; of course research aircraft; and drifting buoys and our upper air sounding network.
sounding network.

Taken together, each of these tools complement each other and form the hurricane detection and positioning network.

As Dr. Sheets mentioned, by far the greatest advantage of geostationary satellites are their ability to detect the time evolution of the hurricane center at approximately half hour intervals. This allows for random track errors to be smoothed out. The disadvantage of course is that position errors increase with distance from the satellite location, a problem we are facing now with the one-satellite system.

The visible sensor on the geostationary satellites offer our best resolution, allowing eye locations to be made for mature storms within 10 nautical miles. However, only about 20 percent of all storms have well formed eyes. The polar orbiting satellites offer the advantage of providing higher spatial resolution than the geostationary satellite and provide a test bed for microwave sensors. One of the disadvantages of a polar orbiting platform, as has been mentioned, is that the orbital path times do not always correspond to the National Hurricane Center operational deadline and may not always provide timely information.

In 1987, a new microwave sensor, called the Special Sensor Microwave Imager was flown on an Air Force satellite. Preliminary studies suggest that this sensor may not be capable of measuring surface winds in the top of the cyclone inner core, only on the periphery.

To go on to the radar systems, since 1950 or so when the National Weather Service WSR-57 radar network was initiated, coastal radars have been used to track storms approaching the coast and viewed as the last line of defense in tracking storms. Airborne radar has been used on our reconnaissance aircraft as well for locating storm centers when penetration of the storm was not always possible.

The land-based radars have the advantage of providing continuous monitoring of storm location as the storm approaches the coast. They can resolve some of the short period track oscillations and help pinpoint exactly where the landfall will occur. However, beyond about 170 nautical miles, other techniques have to be used. And that is where the aircraft come in handy. The aircraft reconnaissance we view as the most accurate method for fixing storm center locations and has been used operationally since the early 1950s. Since the early 1960s, the center position errors of the storm center have decreased from something on the order of 50 to 60 nautical miles to something less than five nautical miles at present.

In the early 1990s the new global positioning satellite system will enable us to further reduce aircraft positioning errors to less than one nautical mile. So the position error of the storm center can be viewed as consisting of really two parts. One part is due to the aircraft navigation error we talked about. The second part is due to the storm center position, locating the storm center position relative to the aircraft. So the overall accuracy depends not only on the flying skill of the crew and the size of the eye, but it also depends on the frequency of fixes in order to resolve the short period track oscillation of the eye and the eyewall complex. These short period oscillations tend to be on the order of 10 to 20 nautical miles in space and have a period of about two to six hours. So therefore, fixes of the storm center roughly every one and a half to three hours are really required to resolve these short period oscillations. The reason they have to be resolved for track prediction purposes is that a smooth track indicating long-term trends in storm motion is required for input to models. So before we can do this, we need to know the shorter period oscillations. So this can be achieved by smoothing the short term oscillations if sufficient fixes are available to resolve them.

Another big advantage of the aircraft is that it can be scheduled to provide the timely position information to the forecaster, providing the latest information right up to the forecast deadline. Aircraft can also detect the location of major principal rain bands that are often accompanied by secondary wind maxima. Sometimes these secondary maxima can cause as much or more damage than the eyewall itself. These principal rain band features are unfortunately often obscured from satellite view.

Now we like to combine these aircraft observations with surface observations as well. The surface observations from ships are not as important as they were in the pre-satellite era because they have all these other sensors. However, the ships, buoys and other surface observations are viewed as complementary data. Surface reports from fixed and drifting buoys are especially helpful in complementing aircraft reconnaissance since they provide position confirmation of circulation while the storm is still at sea before it has made landfall.

Mr. Lewis. Dr. Black, may I interrupt you a moment?

Dr. Black. Sure.

Mr. Lewis. You just said that the buoys assist——

Dr. Black. Correct.

Mr. Lewis [continuing]. The aircraft reconnaissance in helping pinpoint the storm. If the aircraft reconnaissance was not there, what would the buoys do for you?

Dr. Black. They would still provide information. The difficulty with the buoys at present is there are so few. The aircraft can go right to the storm location, provide detailed information at the flight level of the aircraft. The buoys, where they are located, provide a point at the surface that we can use to calibrate the aircraft observations in trying to get the surface wind estimates. So the basic problem with the buoys is there is just not enough of them.

Mr. Lewis. Thank you, I just wanted to make that point for the record.

Dr. Black. Thank you.

So as you know, NOAA maintains an array of fixed buoys around the continental U.S. and the Gulf of Mexico. However, we have experimented recently with the less expensive expendable mini-drifting buoys which can be deployed from our aircraft. So in this regard, the deploying of an array of inexpensive drifting buoys in the western Atlantic and Caribbean as was done on a trial basis by the way in 1985, offers a reliable means of tracking developing systems from the surface. By the way, the motivation for doing this was when we had a GOES satellite outage in 1985 similar to the one we have now. The deployment of a smaller array of buoys just ahead of the storm prior to landfall, as we also did experimentally in 1984, offers the possibility of detecting any unexpected track changes prior to landfall and to complement or backup the aircraft, satellite and radar positioning. The more confidence the forecaster has in the position, initial position of the storm or any sudden position changes, the greater we feel the opportunity to narrow the warnings on the coast and save some of these preparation costs that have been mentioned.

Now for storm surge information and coastal warning, it is important to know the surface wind distribution as well as the maximum wind varying at the center. Low and high cloud motions detected by geostationary satellites are used to infer winds at the lower and upper troposphere, but these methods are not helpful in estimating the surface peak winds or the profile. A method of cloud pattern identification referred to as the Dvorak method, is used to estimate the maximum wind in hurricanes using either geostationary or polar orbiting satellite, visible or infrared images. This method is used worldwide to estimate hurricane intensity especially where there are no aircraft observations, but plays very little role in really estimating the wind field distribution itself. The accuracy of this method, this technique, compared to the aircraft observations is being investigated by Professor Gray.

New earth satellite microwave sensors, such as the special sensor microwave imaging which I mentioned earlier, may be useful in estimating the extent of gale-force winds at the periphery of the storm. This sensor was launched on an Air Force satellite about a year and a half ago. Studies of the accuracy of these gale-force wind radii showed that for cases without aircraft reconnaissance observations, gale force wind radii estimates in the hurricane advisories exceed satellite estimates by a factor of two. However, the cases with aircraft reconnaissance, advisory gale force wind radii were in close agreement with the satellite values.

So this sensor we feel is going to be useful for only the outer wind distribution mapping and not the winds in the inner core.

Mr. SCHEUER. Can I ask you a question?

Dr. BLACK. Yes.

Mr. SCHEUER. What is the status of the split window microwave radiometer that is to be placed on NASA's polar platform space station?

Dr. BLACK. Okay, that is presently a proposal we have advanced for the space station. It involves taking the technology and the things that we have learned from the airborne step frequency and microwave radiometer that Congressman Lewis mentioned earlier and putting it on a satellite platform with very fine spatial resolution. This is an instrument designed by Harris Corporation and NOAA and it is really the only proposal I know of right now that will have the capability of measuring the surface winds at the—the surface maximum wind near the storm center. It will have approximately an eight kilometer spatial resolution, but it is right now only in the planning stages.

Mr. SCHEUER. So do you think it is going to be funded?

Dr. BLACK. Well the preliminary indication is that it will not be funded at the present time, but we have hopes that we can pursue this proposal further. But at the present time, it has been turned down.

Mr. SCHEUER. Well we will be in touch with you about it.

Dr. BLACK. We feel that the proposal has a lot of promise for the hurricane problem, but perhaps the importance of the hurricane problem has—I feel may not have a terribly high visibility in NASA which is the agency that would have to fund this and bring it forward.

So if I could move on to comment on the next generation radar or NEXRAD, it is the follow on to the land-based weather radar system that will be available in the 1990s. These will be able, through the use of measuring Doppler velocities, to provide maximum wind estimates within 100 nautical miles of their radar as the storm approaches. So this could be a very useful tool that will provide actual wind velocities as the storm approaches in addition to simply the center position.

Airborne Doppler radar can derive inner core winds within 50 nautical miles of the storm center at present on the NOAA aircraft, at one nautical mile intervals from roughly the surface to 35,000 feet. This represents the only method presently available for determining observationally the full three-dimensional hurricane wind field. By this coming hurricane season, both NOAA, WP-3 aircraft will be equipped with these Doppler radars—they are now in fact. New generation computers, scheduled to be available for the NOAA aircraft within the next three to five years will allow the processing of the Doppler winds in a real time mode and that information to be transmitted to forecasters. Now this we view as a real breakthrough because it provides a lot of the mid-level data that Dr. Gray was talking about that we really have no other means of obtaining right now.

A new instrument has been tested for use on the NOAA aircraft over the past several years to remotely sense the surface wind from any altitude, including any future high-flying jet aircraft that we were discussing in rain or shine and at nighttime or daytime. This instrument is the stepped frequency microwave radiometer, to which I referred a moment ago. It is capable of measuring the surface wind with an accuracy of roughly three knots. And if I could just add, as one who has flown many hours at 500 feet in hurricanes and nearly stalling an airplane on one occasion, I have had a lot of personal motivation to develop this instrument because it is not very comfortable flying that low. We would love to be able to make these surface wind measurements from a higher altitude. At present this is the only sensor capable of measuring the surface winds at the inner core of the storm and with the possibility of resolving the 20 knot uncertainties that Dr. Sheets mentioned in the storm surge calculations—to actually make the measurement at the surface, not at flight level. The stepped frequency radiometer will be able to transmit surface winds to the National Hurricane Center in real time during the 1989 hurricane season. This instrument, by the way—we have found that it can be incorporated into this IWRS system, the improved weather reconnaissance system, of the Air Force, it has essentially a plug-in module. We looked at that question about a year ago.

The advent of these inexpensive—well let me pass on that.

In concluding, I would just like to say that our ability to monitor the inner core of hurricanes has improved dramatically over the past several years through the use of satellites and more sophisticated aircraft computers, navigation systems, aircraft satellite communication systems. But I do not think this is true of the environment around the storm. We have mid-level data from the weather ships and the piston aircraft that Dr. Gray mentioned have really gone away. We have been lucky to hold the line on forecast accuracy in view of losing these observations that are "in the right place" and have been taken away and been replaced by other surface or cloud observations.

Omega dropwindsondes which have been used on experimental basis in the environment of about six experimental cases since 1982 have demonstrated the ability to resolve small-scale features in the mid-level flow pattern in the environment of hurricanes which have not been resolved by other sources of data. These Omega dropwindsondes we feel can help maybe fill the gap in the mid-level observations because really hurricanes are like a cork in a stream. You have to—in order to find out what the cork is doing, you have to measure what the stream flow is. So that is what we are trying to do with these Omega dropwindsondes instruments.

New tools that could improve the frequency of reliable soundings in the tropical cyclone prone areas are also the very high frequency and ultra high frequency atmospheric profilers that are now planned for the midwest. One would expect that installation of profilers around the Caribbean, Gulf of Mexico and east coast states would have an impact on improving the description of the environmental flow around tropical storms.

So in closing, I would say that the technology is available to fill these observational data gaps at present. Model outputs are only as good as the inputs.

Mr. Chairman, this concludes my prepared statement and I thank you for the opportunity of presenting this testimony.

[The prepared statement of Dr. Black follows:]

TESTIMONY OF
PETER BLACK
METEOROLOGIST
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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

BEFORE THE

SUBCOMMITTEE ON NATURAL RESOURCES, AGRICULTURE RESEARCH AND ENVIRONMENT

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

U.S. HOUSE OF REPRESENTATIVES

APRIL 7, 1989

Mr. Chairman and Members of the Subcommittee:

My name is Peter Black. I am a research meteorologist with the Hurricane Research Division, Atlantic Oceanographic and Meteorological Laboratory, of the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce. I appreciate the opportunity to discuss hurricane forecasting and surveillance. The Hurricane Research Division studies hurricanes through observational and theoretical studies and computer simulation.

INTRODUCTION

Precise estimation of surface winds associated with a hurricane is necessary for issuance of warnings by the National Weather Service's (NWS) National Hurricane Center (NHC). This requires an accurate knowledge of the forecasted storm track and intensity which, in turn, requires knowledge of the storm's initial position and surface wind distribution prior to the

This summary concentrates on assessing the methods presently in use for determining hurricane position, intensity, surface wind distribution and environmental steering flow. The accuracies as well as the strengths and weaknesses of the various observational tools are discussed. The areas where each method is unique, redundant and complementary are mentioned. A view of possible improvements to the hurricane observing system available within the next 5 years is presented.

INITIAL POSITION ESTIMATION

In the United States, the tools available for hurricane position estimation are the following:

- geostationary satellites: visible and infrared sensors
- polar orbiting satellites: visible, infrared and microwave sensors
- radar: ground based, skywave and airborne
- aircraft
- buoys

Each of these tools has its own advantages and disadvantages. Taken together they complement each other and form the hurricane detection and positioning network.

Geostationary Satellites

By far the greatest advantage of the geostationary satellite is its ability to detect the time evolution of the hurricane center. Frequent center positions (nominally computed at 3-hour intervals, but available at one-half hour intervals) are advantageous because random errors, as well as short period track oscillations, can be smoothed out. A disadvantage is that for storms near the satellite's horizon, parallax can lead to large position errors. With a two-satellite system, this affects storms only in the eastern and central Atlantic. But for a one-satellite system, this region moves closer to the U.S. east coast.

a. Visible

This sensor has the advantage that it has a very fine spatial resolution of one-half nautical mile (nm). This allows precise eye locations to be made for mature storms, nominally within 10 nm. However, there are six basic cloud patterns which are used for estimating center positions, of which only about 20 percent are well-formed eyes. For storms without eyes, the high spatial resolution allows low level swirls to be detected, as well as the centroid of a cluster of overshooting thunderstorm turrets, both of which may indicate storm positions. The location error for the weaker systems is considerably larger, on the order of 15-20 nm. The disadvantage of this sensor is that it works only during daylight hours.

b. Infrared

This sensor has the advantage that it can provide location information throughout the day and that it can provide warm core locations for centers which may be obscured visually by high cirrus clouds. The disadvantage is that it has a coarse spatial resolution of four nm and that cold upper clouds are more prominent than low warm clouds, a situation that sometimes leads to misplacement of developing systems. This misplacement may be due to failure to detect the low level, warm cloud circulation center, obscuration of the circulation center by intense convection or detection of an upper circulation center which is displaced from the low level center. The location error may vary from 20 to more than 100 nm.

Polar Orbiting Satellites

The polar orbiting satellites offer the advantages of providing higher spatial resolution for infrared and microwave sensors than from geostationary satellites and provide a test bed for new remote sensing technology. They complement the geostationary satellites during periods of malfunction and eclipse. Another advantage is that they scan beneath the satellite along its subpoint track and hence do not suffer from parallax errors. The disadvantage is that observations are available only twice daily. The United States presently has the NOAA system and the military Defense Meteorological Satellite Program (DMSP) system. Images from the latter are not available for interpretation at the NHC, but position information is relayed via the Air Force Global Weather Central. The orbit pass times do not always correspond with NHC operational deadlines and thus may not always provide timely information.

a. Visible

The DMSP satellites are equipped with a low light level sensor that allows moonlight illuminated visible images (for days with one-quarter moon or greater) to be used for location determination. Otherwise, visible resolution is the same as the geostationary satellites.

b. Infrared

The advantage of infrared polar orbiting sensors is that they have a better spatial resolution than the geostationary satellites, on the order of one nm. This improves their accuracy for storm location over geostationary satellites.

c. Microwave

Several microwave sensors have been tested for use in determining hurricane locations.

Two research sensors on the Seasat satellite in 1978 showed some promise for detecting the surface wind center of hurricanes. These were the Seasat A Scatterometer System (SASS) and the Scanning Multichannel Microwave Radiometer (SMMR). The former had a resolution of 27 nm. This sensor measured the backscattered energy from surface capillary waves from which was inferred surface wind speed and direction. The disadvantage of the system was that the measurements were subject to degradation due rain attenuation in the storm's inner core. The SMMR was a passive system that operated at four frequencies and had resolutions ranging from 10 to 50 nm. This sensor measured the emissions from the foam covered sea surface, plus rain emissions, and inferred wind speed and rain rate.

In 1987, an improved version of the SMMR, called the SSM/I, was flown on the Air Force DMSP satellite with a nominal 15-nm resolution. Although the data have not yet become operationally available to forecasters, the SSM/I is designed to be the first operational microwave sensor.

Radar

Since the mid-1950's, when the NWS's WSR-57 radar network was initiated, coastal radars have been used to track storms approaching the coast. Airborne radar has also been used for locating storm centers when penetration of the storm center was not possible. Since 1975, over-the-horizon, skywave radars have demonstrated the capability to detect storm centers from remote sites thousands of miles away. However, these have never been used operationally in the United States.

a. Land-based

Land-based radars can detect storm centers at a maximum range of about 175 nm. They have the advantage of providing continuous monitoring of storm location as the storm approaches the coast. They can resolve short period track oscillations and help pinpoint where landfall will occur. However, beyond this range, other methods must be used. The radars complement satellite and aircraft locations and provide a great degree of confidence that sudden changes in track will be detected. The disadvantage is that beyond about 75 nm, the radar beam is scanning the upper regions of the storm. This could cause a displacement of the center by up to 10 nm due to tilting of the vortex with height and due to the expansion of the eyewall with height.

The primary method for radar detecting of the storm center is to subjectively determine the center of the precipitation-free eye region, a method that may prove difficult if only a portion of the eyewall exists or can be detected. While other techniques are available when no obvious eyewall exists, they may have errors of 10-20 nm or more.

b. Airborne

Center location with airborne radar was used extensively during the early days of hurricane reconnaissance when aircraft limitations sometimes prevented direct penetration. However, in the late 1970's and 1980's, airborne radar has been used primarily as a navigation aid to indicate storm-center location at large range and to indicate dangerous quadrants and bands where severe turbulence would be expected. The advantage of airborne radar is that it can be taken to the storm rather than waiting for the storm to come within range of a fixed radar.

c. Skywave

The over-the-horizon, or skywave, radar was used experimentally in 1975 and 1977 to detect Gulf of Mexico storms from the radar site in California. This method is based on the measurement of Doppler velocity and backscattered energy from ocean surface waves. A high frequency signal is transmitted and reflected from a highly ionized layer in the ionosphere to the region of interest on the sea surface. The information from the returned pulse is then processed to compute the direction of surface wave propagation. Centers determined from this method were found to have errors of 5-20 nm, with an average error of 10 nm. This technique has the advantage of remotely sensing the surface center, as a satellite microwave sensor would do, but with existing facilities and at low cost.

Aircraft

Aircraft reconnaissance is the most accurate method for fixing storm center positions and has been used operationally since the early 1950's. The accuracy of this technique has varied over the years depending on the accuracy of the on-board navigation system. The method of navigation used from the late 1940's to the late 1950's was primarily dead reckoning, celestial and radio direction finding (RDF). From the late 1950's to the present, Doppler radar navigation has been the primary source of navigation, with Loran and RDF as backups. On the NOAA aircraft, inertial navigation with Omega updating became the primary method after 1975. Each of these systems suffers its own peculiar type of error. The Doppler suffers from errors caused by ocean currents and moving sea spray. It also suffers from attenuation in heavy rain, causing the system to measure the aircraft airspeed rather than ground-speed. Inertial systems suffer a long term drift plus a 2-hour oscillation (known as the Schuyler oscillation). Over the years, center position errors have decreased from the order of 50-60 nm in the early 1950's to 10-20 nm in the Doppler era, to less than 5 nm presently in the inertial era when additional aids such as Loran, RDF, or Omega are used to periodically remove the long-term drift error. In the early 1990's, the global satellite positioning system will be available that will further reduce aircraft positioning errors to less than one nm.

The position error of the storm center consists of two parts--one part due to aircraft navigation error and a second part due to storm center positioning relative to the aircraft. This latter component depends on estimating the circulation center or calm spot and the point of minimum pressure. These two points do not always coincide. The accuracy depends on the flying skill of the crew, the size of the eye and the intensity of the storm. It also depends on the frequency of fixes in order to resolve short-period oscillations of the center within the clear eye and of the eye-eyewall complex. Since these oscillations tend to be on the order of 10-20 nm in amplitude and 2-6 hours in period, fixes every 1.5-3 hours are required to resolve them. For track prediction purposes, a smooth track indicating the long-term trend in storm motion is required. This can be achieved by smoothing the short-term oscillations if sufficient fixes are available to resolve them, or by attempting to track the center of mass of the storm, which is determined as the centroid of the pressure field. This so-called "mass field envelope" center position can be tracked with an accuracy of 5-10 nm.

Another big advantage of aircraft is that they can be scheduled to provide timely position information to the forecaster, providing the latest information right up to forecast deadline. Aircraft can also detect the location of major principal rainbands with secondary wind maxima and heavy rain conditions which may cause as much, or more, damage than the eyewall region. These principal rainband features are often obscured from satellite view.

Surface Reports

Surface reports, as indicators of hurricane position, are not nearly as important now as they were in the pre-satellite era. They are viewed as complementary data. Reports from fixed and drifting buoys are especially helpful in this regard since they provide position confirmation while the storm is still at sea, before it has made landfall. In this regard, deploying an array of drifting buoys in the Western Atlantic and Caribbean Sea, as was done on a trial basis in 1985, offers a reliable means of tracking developing systems. The deployment of a smaller array of buoys just ahead of the storm prior to landfall, as was done in 1984, offers the possibility of detecting any unexpected track changes prior to landfall as a complement and backup to aircraft, satellite and radar positioning. The more confidence the forecaster has in the initial storm position, the greater the opportunity to narrow the warning zone on the coast, and hence save preparation costs for coastal residents.

WIND FIELDS - AERIAL DISTRIBUTION AND MAXIMUM INTENSITY

Geostationary Satellites

a. Visible/Infrared

Low- and high-cloud motions detected by the visible and infrared sensors in a sequence of images are used to infer wind in the lower and upper atmosphere. The low-cloud motions are sometimes useful for defining the radius of gale-force winds in the periphery of the storm, but more often are used together with the high cloud motions for determining the flow in the environment around the storm.

b. Water Vapor Winds

It has become possible, using the 6.7 micron CO_2 window, to track filaments and discontinuities in upper tropospheric water vapor contents using the cloud tracking approach. The accuracy of these winds has been rather poor, with errors on the order of 5 meters per second. Water vapor winds can only be calculated in the clear environment around the storm.

c. VISSR Atmospheric Sounder (VAS)

Using several narrow water vapor absorption lines, it has been possible to retrieve vertical atmospheric temperature soundings in the clear air environment around storms, with varying degrees of accuracy. The pressure field is then inferred from the thermal field, and winds are calculated from the pressure fields.

Polar Orbiting Satellites

a. TIROS Operational Vertical Sounder (TOVS)

This sensor is a microwave device that recovers temperature soundings in cloudy, as well as in clear conditions, but not in heavy rain. The disadvantages of this sensor are that the data are obtained in swaths at non-synoptic times. Retrievals are limited to the non-rain areas in the environment around the storm.

b. Microwave

Two experimental sensors, mentioned earlier, the SASS and SMMR, were tested on Seasat in 1978 for their ability to measure surface winds in hurricanes. The former measured wind speed and direction while the latter measured only speed. SASS and SMMR wind fields were compared with surface wind fields derived from research aircraft data. Despite rain attenuation problems and large direction errors in some quadrants, the SASS-measured wind speeds showed errors of less than 2 meters per second for winds that were less than 25 meters per second. Average SMMR errors were 3 meters per second, with large underestimates in the inner core area.

The study of the accuracy of gale-force wind radii showed that, for cases without aircraft reconnaissance observations, gale-force wind radii estimates in advisories exceeded the SASS estimates by a factor of 2 on average. For cases with aircraft reconnaissance, advisory gale-force wind radii were in close agreement with the SASS values.

An instrument similar to the SMMR, called the SSM/I, also mentioned earlier, was launched in 1987 on a DMSP satellite and is being evaluated. Comparison with buoys in both the Atlantic and Pacific have shown, after a bias is removed, that agreement is within 2 meters per second in rain-free conditions. Once again, this means that this sensor may map only the gale force winds in the periphery of the hurricane.

One source of microwave surface winds which is available operationally is derived from satellite altimeters. The altimeter as a wind sensor was validated by GEOS-C and Seasat satellites in 1975 and 1978, respectively. It was shown that, along the satellite subpoint track for winds less than 20 meters per second, these instruments were accurate to within 2 meters per second in rain-free regions. Presently, the GEOSAT satellite altimeter is measuring surface winds. The disadvantage is that the probability of obtaining a pass over a hurricane on any given day is quite low, even less than for the SSM/I.

Radar

a. Land-based

The use of conventional land-based radar to determine hurricane wind fields by calculating echo motions is a technique used operationally in Japan and Hong Kong, but not in the United States. It has been done many times in a research mode, using land-based as well as airborne radar, to determine the field and radial profile of echo winds. By choosing cell centroid motions, a wind field close to cloud base can be derived. By choosing more diffuse, stratiform cells, a mid-level wind field can be derived. A short 10-minute interval is usually sufficient for echo motions to be derived.

The NWS's next generation radar (NEXRAD) land-based system will be available in the mid 1990's and will be able to determine radial Doppler velocities, which will provide maximum wind estimates within 100 nm of the radar as the storm approaches. It may be possible to derive total wind fields, in small regions where radar coverage from two radars overlap, or by combining two sweeps from the same radar several hours apart as the storm moves past the site.

b. Airborne

The airborne Doppler radar can derive inner core winds within 50 nm of the center at one-half nm intervals in the horizontal and in the vertical from 1500 to 35,000 ft altitude. Accuracy of the Doppler winds appears to be better than 2 meters per second. This represents the only method presently available for determining the full three-dimensional (3-D) hurricane wind field. However, by this coming hurricane season, both NOAA WP-3D aircraft will be equipped with Doppler radars. New generation computers, scheduled to be available for the NOAA aircraft within the next 3-5 years, will allow the Doppler winds to be calculated in real-time on board the aircraft and to be transmitted to forecasters.

Aircraft

Flight-level winds are measured by the Air Force and NOAA using two different methods. The former use manually-observed readings from an Omega-aided Doppler navigation system to calculate roughly 1-minute average winds at 10-15 minute intervals. NOAA uses computed 1-second values from an Omega-aided inertial navigation system to calculate 1-minute average winds at 1-minute intervals. NOAA flys at either 1500 feet or 5000 feet. The Air Force is required to fly at 10,000 feet when the winds exceed 50 knots. Various objective analysis schemes are being tested for use with the NOAA data to derive the complete flight-level wind field and the time rate of change of the winds along the radial profile and are expected to be operational within the next two years.

A new instrument has been tested on the NOAA aircraft over the past several years to remotely sense the surface wind from any altitude, rain or shine, night or day. This instrument, called the stepped frequency microwave radiometer (SFMR), is capable of measuring the surface wind with an accuracy of 1.5 meters per second. This is the only sensor capable of measuring the surface winds in the inner core of the storm. One shortcoming is that the instrument measures only the speed. The SFMR will be able to transmit surface winds in real time by the 1989 hurricane season when the satellite communications system is upgraded.

Buoys

The advent of inexpensive air-deployable drifting buoys has makes it possible to consider deriving the hurricane wind field from a network of these buoys deployed just ahead of potential landfalling hurricanes. It was shown in 1984 that an array of drifting buoys could be dropped just ahead of a hurricane and that a composited storm-relative wind field could be computed over a period of 12-24 hours that resembled the surface wind field derived from the near-instantaneous flight-level data. Whereas the buoys used in 1984 cost $20K and had to be dropped from a C-130 aircraft, the newer ones cost $5K, are much smaller, and can be dropped by the NOAA WP-3D.

THE HURRICANE ENVIRONMENT

Our ability to monitor the inner core of the hurricane has improved dramatically over the past several years, through the use of satellites and more sophisticated aircraft computers, navigation systems and communication systems.

Omega dropwindsondes have been used on an experimental basis in the environment of hurricanes six times since 1982 and have demonstrated the ability to resolve small-scale features in the mid-level flow pattern in the environment of hurricanes that were not resolved by other types of data and that did have an effect on storm motion.

New tools that could improve the frequency of reliable soundings in the tropical-cyclone-prone areas are the very-high-frequency (VHF) and ultra-high-frequency (UHF) profilers that are now planned for the Midwest. One would expect that the installation of profilers around the Caribbean Sea, the Gulf of Mexico, and East Coast States would have a dramatic impact on improving the description of the environment flow around tropical storms and could lead to improved forecasts.

Mr. Chairman, this concludes my prepared statement. I will be happy to answer any questions you may have at this time, or provide for the record any other information requested.

Mr. **Lewis**. Thanks for being with us, Colonel Morris.

Well gentlemen, I would like both of you to comment, if you could, there are many research areas and needs in hurricane surveillance, data processing and related fields. I would like you to comment on the relative importance of each and the likelihood that an effective research program will be underway within the next two years. Now Dr. Gray, you did comment on research with the reconnaissance data. I have talked with a number of gentlemen in Oklahoma City at the National Weather Center and the Severe Storm Center, particularly on the Doppler radar and the NEXRAD installations. This is all well and good to say that is going to be here, but we do not have a very good track record with installations. Now with the first NEXRAD going in around the Pensacola area I believe in 1991, something like that, and it looks like it will be 1994 before they are positioned around Florida. That is all well and good, but they also told me they just started the blasted research in the three-dimensional Doppler and they ran down to the Gulf to look at Gilbert, they did a lot of things, but we have still got a lot of work to do in that area. I am very much concerned that it will be awhile before we get those things in. Where do you think we stand with the NEXRAD and Doppler and as far as what we should be doing in the next two years. And you feel free to comment too, Dr. Sheets.

Dr. **Black**. If I might comment, Mr. Chairman, I just came back from attending the recent Conference on Meteorology in Tallahassee at which this program was discussed at great length. One of the things that is just beginning now is to study some of the airborne Doppler observations and to develop ways in which computer algorithms can be used most efficiently based on the observations we already have to apply to the NEXRAD systems and how best we can develop computerized methods of tracking storms, estimating maximum winds and so on, but I agree with you completely that this algorithm development has lagged a lot behind the development of programs for severe storms. That seems to be the primary priority right now and the tropical storm algorithm work, while being done, is at a much lower priority.

Mr. **Lewis**. Dr. Gray.

Dr. **Gray**. Well I have a philosophy that I have observed over many years, that this country puts so much into new technology, I mean we spend so much money for new technology and so little to look at already collected data that could feed back in important ways and make some of the new technology not quite as needed or as valuable, and we do not do this. It is very difficult to get a little money to do tropical storm research. Some people may feel I am tooting my own horn and looking for money, but I am not just speaking for myself. This has been traditionally the way it is and it is unfortunate because if you would just spend a little money for research, it is time downstream. If you really want to build for the mid-1990 system to get as much out of them as you can, you have got to start researching, you have got to start looking at already collected data. And that is not as glamorous, it is tedious and so on and people shy away from doing it, and it is unfortunate that we are not making—we are not effectively utilizing our data that we already have. And I think it is time that we split some little bit of consideration in utilizing already collected data that will, if they are researched right, will eventually feed back and help in this program.

Thank you for making those statements.

Mr. LEWIS. Dr. Sheets.

Dr. SHEETS. The NEXRAD, you are right, it is NEXRAD Doppler radars that are scheduled in the midwest primarily, there are a few otherwise, up here at Melbourne because of the space center.

Mr. LEWIS. I said Pensacola but I meant Melbourne.

Dr. SHEETS. It is Melbourne at the space center, and also at Washington and Norman, Oklahoma. Those are the first three. We are scheduled here in south Florida, the first one in Miami in November of 1992.

And so indeed, I think it is appropriate that the emphasis at this time where those are going to be spread out over the midwest should be for the severe storm activity and developing all those algorithms because they will not be along the coast for another few years. So that portion of the development process started slow. There is a finite amount of resources available to do these developments and I think it was appropriate to put those resources there now because of where the radar systems are going to be. But we are now starting to bring this level up as far as the hurricane, tropical cyclones are concerned, and indeed that will be increasing over the next year or so.

Mr. LEWIS. Well the reason for my question was to again try to verify the need for aircraft surveillance. I have been hearing the argument about satellites and buoys and NEXRAD and Doppler and somebody is fooling somebody because none of this stuff we are talking about is in hand, so to speak. Yeah, we have had buoys since Christopher Columbus but they are not going to tell you which way a hurricane is going.

Dr. SHEETS. It only measures where it is at.

Mr. LEWIS. That is exactly right.

Dr. SHEETS. It cannot move with the system, they are deployable buoys and in terms of the Doppler radar, the NEXRAD radars, that is basically for fine-tuning at the coast. The warnings are already basically there and so what you are doing with those is fine-tuning, very important but it still does not help you in the initial warning process.

Mr. LEWIS. I appreciate that. I guess maybe the final question I would have is if the aircraft surveillance was terminated as of today, what kind of shape would we be in in order to provide the most accurate landfall forecast on our coasts?

Dr. SHEETS. No one wants to answer that except me I guess. Well I think that the studies that I have conducted and our staff has conducted and partly with the things that Bill Gray is working on and also in response to the Congressional action there, my personal studies have indicated roughly a 20-percent degradation in our forecast errors at 24 hours, roughly that. But there are the extremes that Bill had mentioned, and I believe in your opening statement you mentioned some of those that may be much larger than that on an individual basis, the individual storm situations. And where we would be at is we would have to do considerable over-warning, more so than we do today. And my concern is with the populations that we have and the exposure that we have, if we do that, indeed the cry wolf syndrome will come home to haunt us and we will lose lives as a result of that.

Mr. **Lewis**. Dr. Black?

Dr. **Black**. I would like to comment on that also because I feel, in terms of the research community, if the reconnaissance and aircraft surveillance were discontinued, we would have wasted a lot of resources that in our laboratory we have been devoting to developing ways for the Hurricane Center to better use the aircraft data in a real time mode. We have been leaning more to the philosophy of every research project that is done in terms of basic research to try to understand the dynamics of the tropical cyclone, we want to be able to have an operational component that would make this data available to the forecasters when it is observed or shortly thereafter and then easily digestible. And we have developed—brought a lot of our personnel and computer resources to doing that and also in terms of developing new sensors like the stepped frequency microwave radiometer.

We are getting to the stage, I think, in the next couple of years where we will really begin to see some payoffs at the Hurricane Center and I think it would be quite a shame if just as we are getting to that stage, the aircraft program were cut off.

Mr. **Lewis**. Dr. Gray, would you like to comment on that also?

Dr. **Gray**. Yeah. This country could afford reconnaissance 40 years ago when coastal populations were much less and the GNP of the country was much less. It just does not seem that now with the great property values along our coast, that you would want to not have the best possible forecast you could have. Now the satellite can often do an adequate job, but there will be situations when it will not. And to have the best possible forecast, I would think the general public wants that, and it seems like at this time we definitely need the aircraft data.

I think another big consideration is like in the Pacific, the Air Force has discontinued it there. It's a little different along our southeast coast, there are so many more U.S. lives and property involved but also we have a storm surge problem along the southeast coast and with U.S. interests in the Pacific, we do not have so much of. And this storm surge demands such accurate precision of where the storm is, how the wind distribution is and so on. From my own personal view, it would seem like we just must have reconnaissance data to have the best possible forecast.

Mr. **Lewis**. I would like to just make an observation. I guess it was last July or August, and correct me if I am wrong, Jim, that we had a storm bearing down on Hawaii and they were tracking it by satellite, both ours and someone else's. And they made a decision that we may have to batten down the hatches on two major Hawaiian Islands, things like that. Just by chance they sent into it and found out it was going to miss the blasted islands. So that was in my judgment a good example of why you need all of it. And I think your examples, Dr. Sheets, of we could lose lives and I think that is our priority number one concern in this business.

I want to thank you gentlemen for your testimony and I would like to ask you, Dr. Black, if you think the profiler program should receive a higher priority and if so, could you explain?

Dr. **Black**. I feel that it should receive a higher priority in our part of the world. In the Weather Service I believe it has gone forward with a fair amount of vigor and there is an array of profilers planned for the midwest but primarily the midwest. I feel though that the high spatial resolution, in other words, the very frequent upper air soundings that these profilers could provide for the southeast area of Florida and the Caribbean area as well would be very helpful.

Mr. **Lewis**. Thank you. Do you have any questions?

[No response.]

Mr. **Lewis**. Well thank you very much. We want to thank you for coming and giving your testimony. Dr. Sheets, thank you for staying.

I want to thank Curt for his work and Jim Greene for his and Marty, for yours. Thank you very much.

This hearing is adjourned.

[Whereupon, at 5:20 p.m., the Subcommittee was adjourned.]

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